3D Seismic Reservoir Characterization and Delineation in Carbonate Reservoir*

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Abstract

West Betara (WB) Field is located in South Sumatra Basin, Indonesia, tested hydrocarbon (Gas) from carbonate reservoirs of the Batu Raja Formation. This is an interesting challenge to describe the lateral distribution and its property within carbonate reservoir at minimum data information. The objectives of this study are to delineate carbonate reservoir distribution including the laterally rock properties by using seismic reservoir characterization methods.

The availability of 3D seismic data, DST's data, conventional well data as wireline and mudlog data is very helpful in answering the challenge. By optimizing well data information, the sensitivity analysis can be generated from wireline log data to determine gas zone and appropriate seismic reservoir characterization method. 3D Seismic data provides helpful inter-well information for determining and visualizing reservoir structure and rock properties at the present day, they help us to generate seismic inversion model and multi-attribute analyses to predict reservoir boundary and its property distribution laterally.

The sensitivity analysis of cross-plots combination from Gamma Ray Log, Acoustic Impedance (AI) Log derived from Sonic and density log, Neutron-Porosity Log and Resistivity Log shows good separation for gas zone in carbonate reservoir. The results help us to predict reservoir boundary and its property distribution laterally by seismic inversion and multi-attribute method in our 3D seismic data. The Gamma ray (low value) and AI (high value) maps are showing consistency of carbonate reservoir delineation. In line with Gamma ray and AI maps, the porosity map of the carbonate reservoir shows gas zone (high value) with certain pattern and it is consistent with tested well data. The result of the study has been successfully delineating carbonate reservoir distribution including the property laterally within West Betara Field.

Introduction

West Betara (WB) Field is located within the Jabung Block, northern part of South Sumatra Basin (Figure 1). Operated by PetroChina International Jabung Ltd. in partnership with PETRONAS and PERTAMINA HULU ENERGI, this field was discovered in 2004 by WB-1 well, 3D seismic data were acquired and 17 additional wells have been drilled. The WB structure is a typically half-graben feature that became slightly re-inverted by later younger tectonism event in Plio-Pleistocene time. This feature becomes a common play type in the area of the Jabung Block.

A chronostratigraphic scheme in Figure 2A, showing the Batu Raja Formation, lies between the Talang Akar and the Gumai Formation. Regionally, marine transgression continued in the Early Miocene with deeper marine shale deposition over the grabens area, and shallow marine conditions over intra-basinal highs and much of the eastern side of the basin. Carbonate production flourished at this time and resulted in the deposition of limestone both on the platforms at the margins of the basin, and as reefs on subtle intra-basinal highs. High quality carbonate reservoirs are common in the south of the basin, but are less frequent in the Jambi sub-basin to the north. This is due to increased sediment input northwards and more pronounced exposure of bioherms enhancing secondary porosity to the south and east. Figure 2B shows the distribution of carbonate facies in the Early Miocene (Ginger and Fielding, 2005).

The proven area of the Formation play fairway lies in the east and south of the basin. The critical factors for the play are reservoir presence/effectiveness (high porosity carbonate reservoirs are concentrated in the east and south of the basin with too much sediment input to the north and a lack of secondary porosity enhancement to the west) and seal (with failed Batu Raja tests on the extreme eastern side of the basin, at the limit of the Gumai Formation seal) (Ginger and Fielding, 2005).

Based on wireline, mudlog and reservoir test data of some West Betara's wells proving the hydrocarbon (gas) existence from carbonate reservoirs of the Batu Raja Formations. These results (Figure 3) are also proving that the carbonate reservoir in the northern part of South Sumatra Basin has hydrocarbon content. To describe the lateral distribution and its property within carbonate reservoir at minimum data information is an interesting challenge and become the main objectives of this study by delineating carbonate reservoir distribution including the property laterally by using seismic reservoir characterization methods. A local cross section of the Batu Raja formation in West Betara field based on well data shows lateral carbonate distribution West to East direction (Figure 4).

Methodology

The sensitivity analysis from log data, Model-Based Seismic Inversion, Seismic Multi Attribute Analysis and Surface Seismic Attribute calculation has been carried out in this study (Figure 5).

Sensitivity analysis was conducted by cross-plotting Acoustic Impedance (the product of density and P-wave velocity) with Gamma Ray and cross-plotting Acoustic Impedance with Porosity. The Deep Resistivity log was used as a color indicator for fluid separation in cross-plot distribution data. The purpose of this analysis is to find physical properties that can separate the prospect zone with non prospect zones in this case we can make some predictions about lithology and porosity properties of the carbonates which is filled by hydrocarbons.

P-Impedance cube was generated by Model-Based Seismic Inversion. Model Based Inversion is the inversion algorithm most useful in a wide variety of circumstances. The output of this inversion is a form of model that can correspond to the input data. This method was applied because in the WB field, there are 17 existing wells as a control.

Multi-attribute analysis was performed for log properties prediction to seismic data based on previous sensitivity analysis. During the analysis it will be produced a seismic volume data or seismic cube with its value in accordance with the log data as input. In this case, Acoustic Impedance (AI), Gamma Ray (GR) and Porosity log are used as input data to change the 3D seismic volume into AI, GR and Porosity volume. The reservoir distributions are determined from surface seismic attributes by statistical calculations using AI, GR and Porosity volume as an input data. The calculation is done by using a certain window analysis from interpreted surface of Top Batu Raja, which represents the interval of carbonate reservoir.

Reservoir mapping and its delineation can be seen from surface seismic attribute results. Gamma Ray and Acoustic Impedance map was created to delineate facies boundary, and Porosity map was created to delineate porosity distribution, which are filled by hydrocarbon. To validate the porosity distribution, which is filled by hydrocarbon, log density and log neutron, was plotted on each existing wells. Correlation between log data and Porosity map are shown qualitatively good.

Result and Discussion

The sensitivity analysis of well data showing good separation between reservoir and non-reservoir, The WBD-8 Well as an example data, the crossplot between P-Impedance and Gamma Ray can distinguish lithologically between carbonate reservoir and shale. Figure 6A shows carbonate reservoir located on the lower zone of the Gamma Ray with high Impedance value. The Resistivity (LLD) color index shows clearly separation between carbonate with gas content (high resistivity value) and no gas content. This carbonate also has high porosity value than shale as shown in Figure 6B. Meanwhile, the carbonate with gas content has little bit higher porosity value than carbonate reservoir with no gas content.

This crossplotting method was applied to log data for all existing wells of WB field. The results shown in Figure7A and B, the analysis summary showed the consistency of data distribution. We can determine reservoir parameter for carbonate with low Gamma Ray (range 50-150 API), low P-Impedance (range 18000-44000 (ft/s)*(gr/cc)) where low P-Impedance with range 18000-27000 (ft/s)*(gr/cc) is carbonate reservoir with gas content and high Porosity with range 0.15-0.3 (fractional).

By using seismic 3D data and log data (P-Impedance, Gamma Ray and Porosity log data), Model-Based Seismic Inversion and multi-attribute analysis was generated and to create the P-Impedance cube, Gamma Ray and Porosity cubes. The result also validated with related well data as shown in Figure 8.

Based on these cubes, the lateral distribution of carbonate reservoir and its porosity can be created separately by using surface seismic attribute calculation. The best fit attribute in this case is Average Magnitude attribute, this operation measures the reflectivity within interval horizon top to bottom carbonate of Batu Raja Formation and may be used as an hydrocarbon indicator and as well as isolated geologic features which express themselves as anomalous amplitudes relative to background values. Figure 9 shows the calculation result of Average Magnitude attribute. Based on the obtained results, there are distribution consistencies from Gamma Ray, P-Impedance and Porosity maps. These three maps showing consistency of carbonate reservoir boundary direct and indirectly. Gamma Ray and P-Impedance maps which representing lithology as shown in Figure 9A and B showing carbonate facies boundary directly. Porosity Map which representing porous zone of the lithology as shown in Figure 9C showing porosity distribution and fit with facies boundary where carbonate with gas content has higher porosity value (red to green color) than carbonate reservoir with no gas content (red to dark blue color).

To see the validity results of the porosity distribution, the Porosity Map was compared with density-neutron log data from existing wells qualitatively. Figure 10 shows the comparison between Porosity Map and Existing log data, it can be seen that existing wells of WBD-2, WBD-5, WBD-7, WBD-8, WBD-9 and WBD-13 have density and neutron separation, which indicates there is a porous layer as a good reservoir with gas accumulation. As shown in Figure 10, good correlation shows that the Porosity Map and density-neutron log data has a fairly relationship, where the carbonate with gas content and the carbonate reservoir with no gas content are distinguishable. In general, with minimum well data information, these methods can be used to delineate the paleo-depositional environment of Batu Raja carbonate reservoir in West Betara field. Based on the high porosity distribution, the next potential target to be drilled located in the southern and southeastern of WBD-8 existing well.

Conclusions

The Carbonate reservoir delineation and distribution with minimum log data information can be done by using seismic reservoir characterization methods. Some sensitivity analyses from log data, Model-Based Seismic Inversion, Seismic Multi Attribute Analysis and Surface Seismic Attribute calculation has been carried out in this study.

The sensitivity analyses of well data showing good separation between reservoir and non-reservoir by crossplotting between P-Impedance with Gamma Ray and P-Impedance with Porosity. The Resistivity (LLD) color index shows clear separation between carbonate with gas content (high resistivity value) and no gas content. This analysis also is the key to generate 3D property volume up to delineation map. The comparison between Porosity Map and Existing log data, it can be seen that existing wells of WBD-2, WBD-5, WBD-7, WBD-8, WBD-9 and WBD-13 have density and neutron separation which indicates there is a porous layer as a good reservoir with gas accumulation. Based on the high porosity distribution, the next potential target to be drilled located in the southern and southeastern of WBD-8 existing well.

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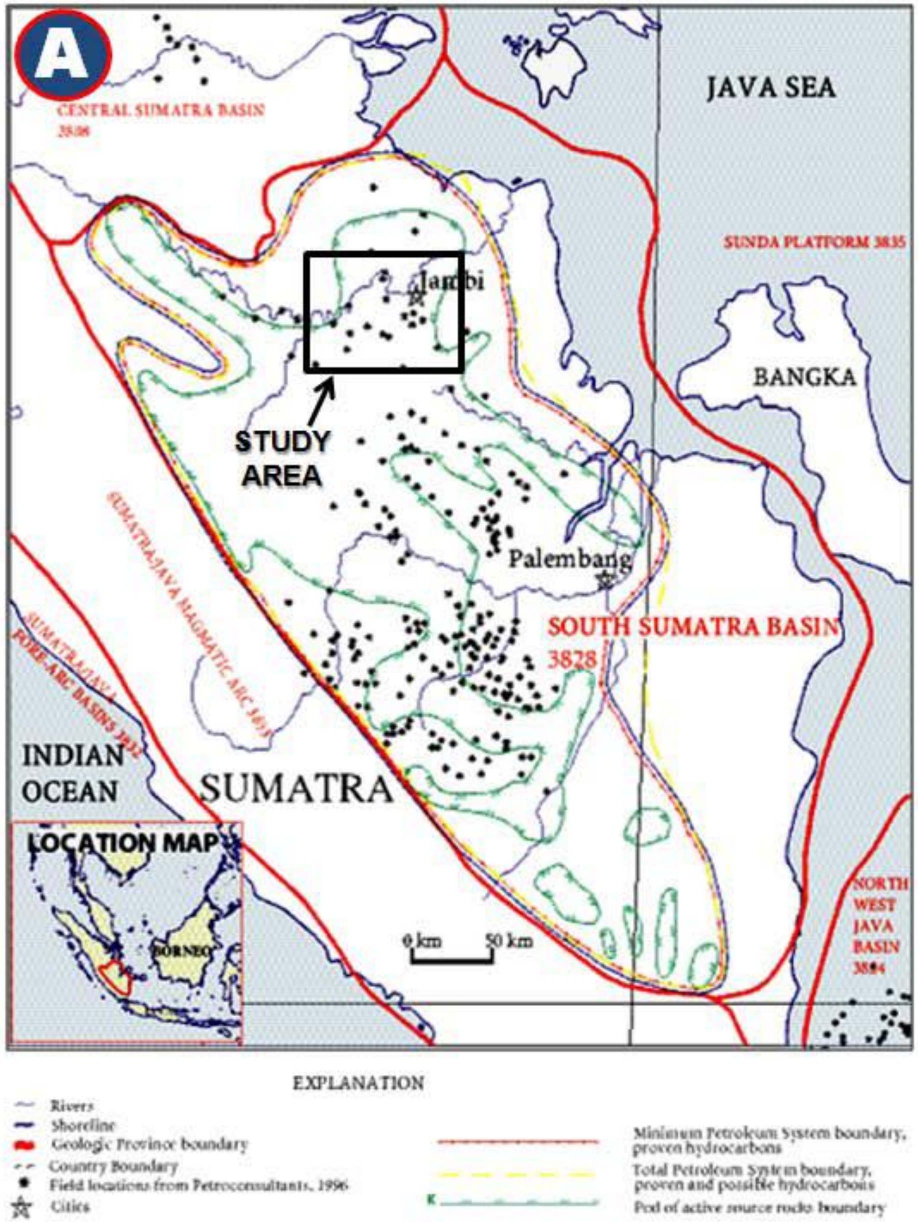

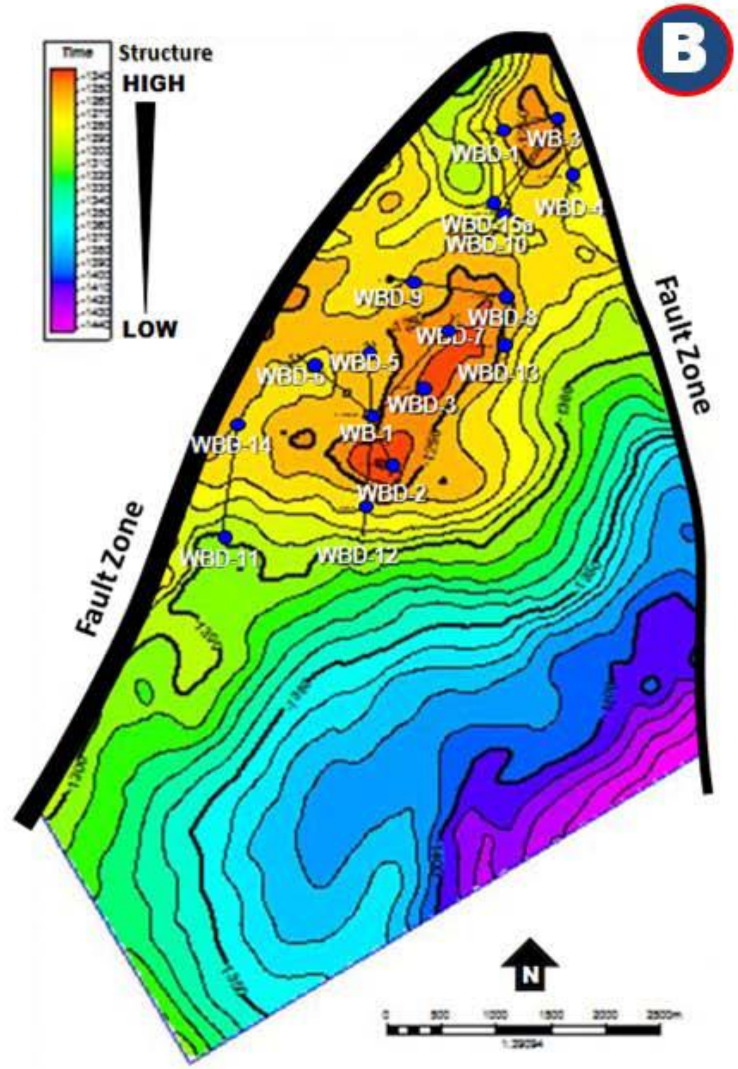

Figure 1. (A) Map of South Sumatra Basin province (modified from Bishop, 2000). (B) Time structure map of Top Batu Raja Formation of West Betara Field.

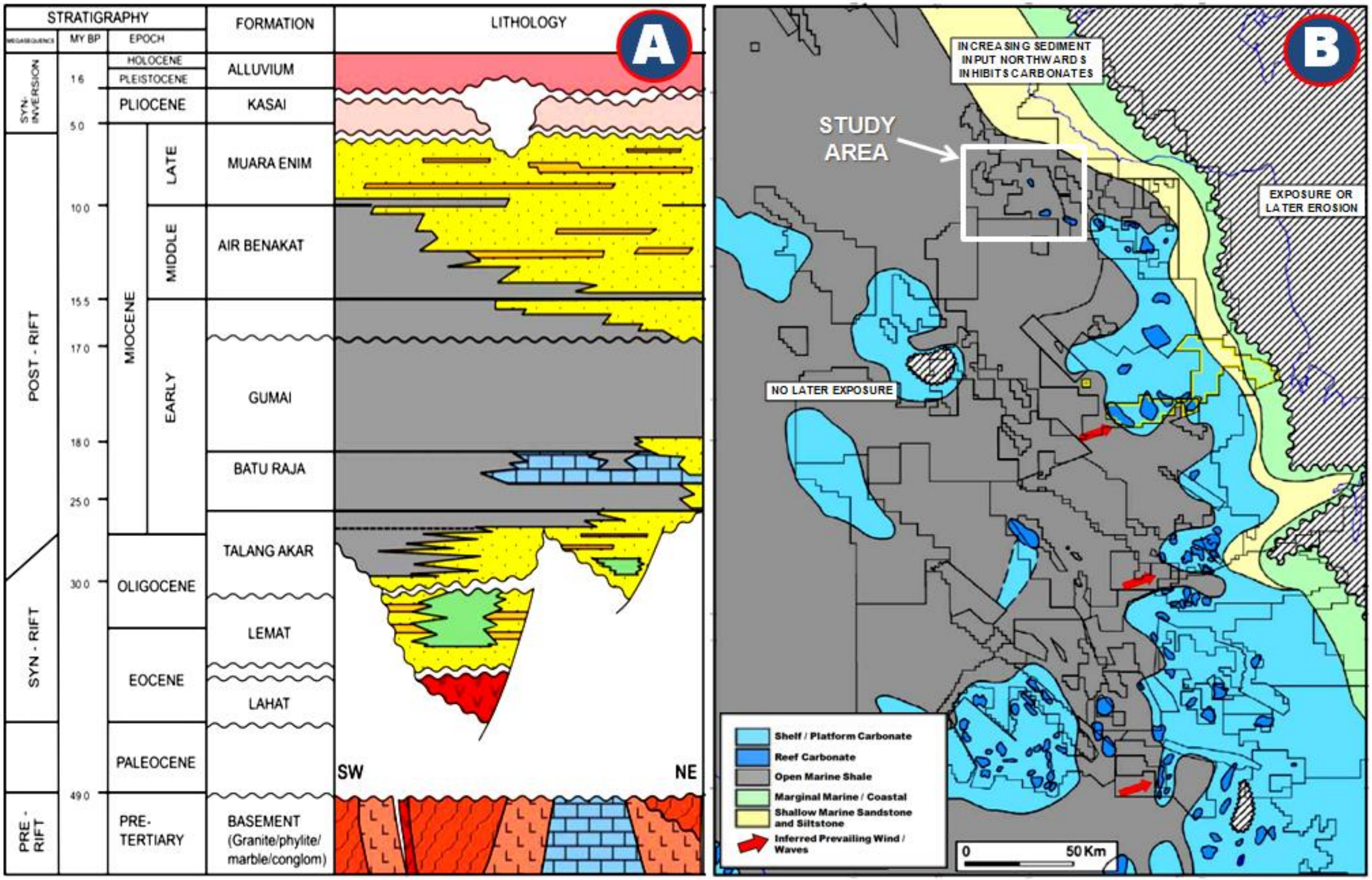

Figure 2. (A) A chronostratigraphic scheme of South Sumatra Basin showing Batu Raja Formation (black square line with light blue color) lies between Talang Akar and Gumai Formation. (B) Early Miocene of Batu Raja Formation paleogeography in South Sumatra Basin (Modified from Ginger and Fielding, 2005).

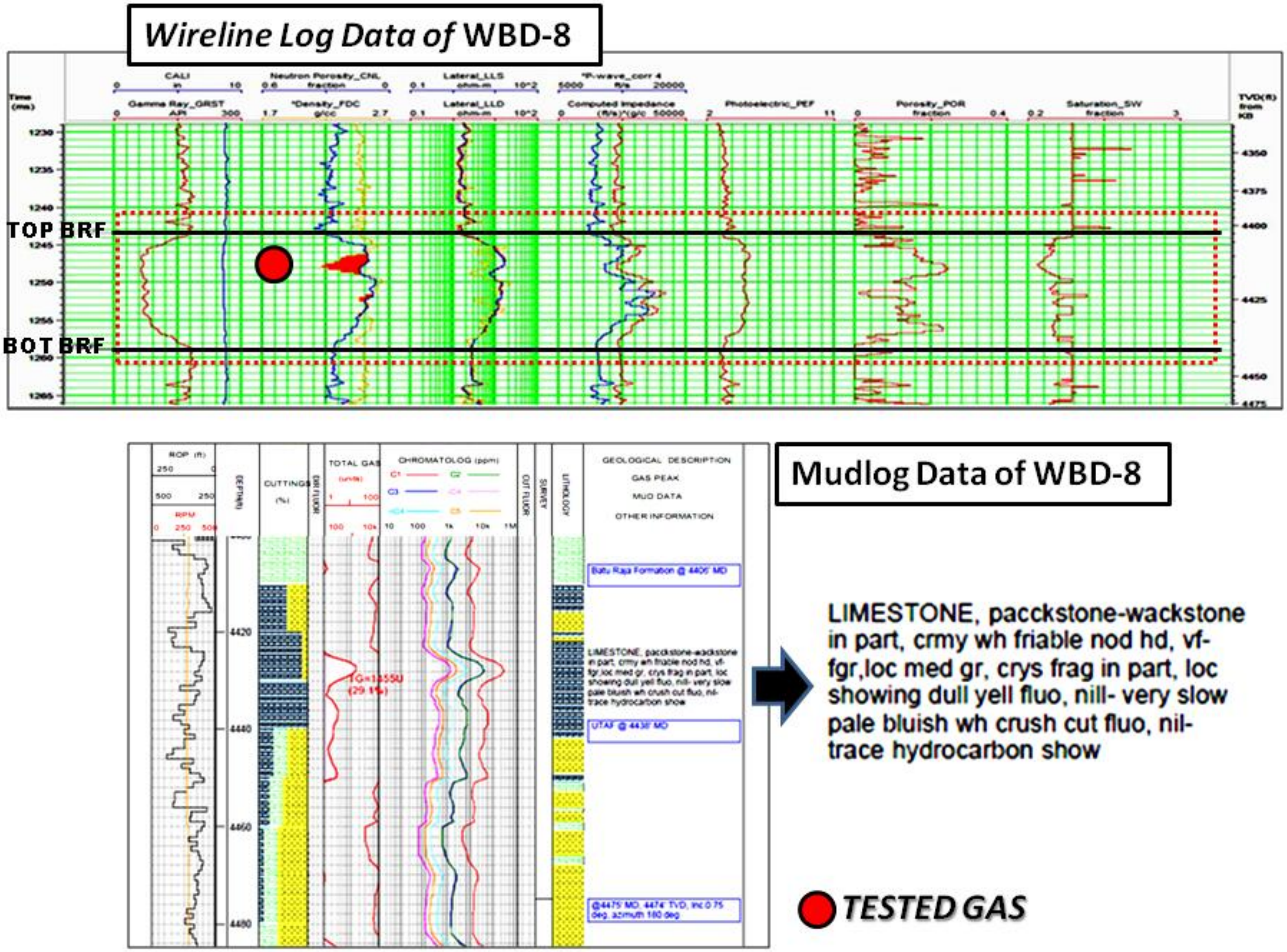

Figure 3. Wireline and Mud log data of WBD-8, one of example well from West Betara Field. The result shows and proves the presence of hydrocarbons (gas) on Batu Raja Formation (BRF).

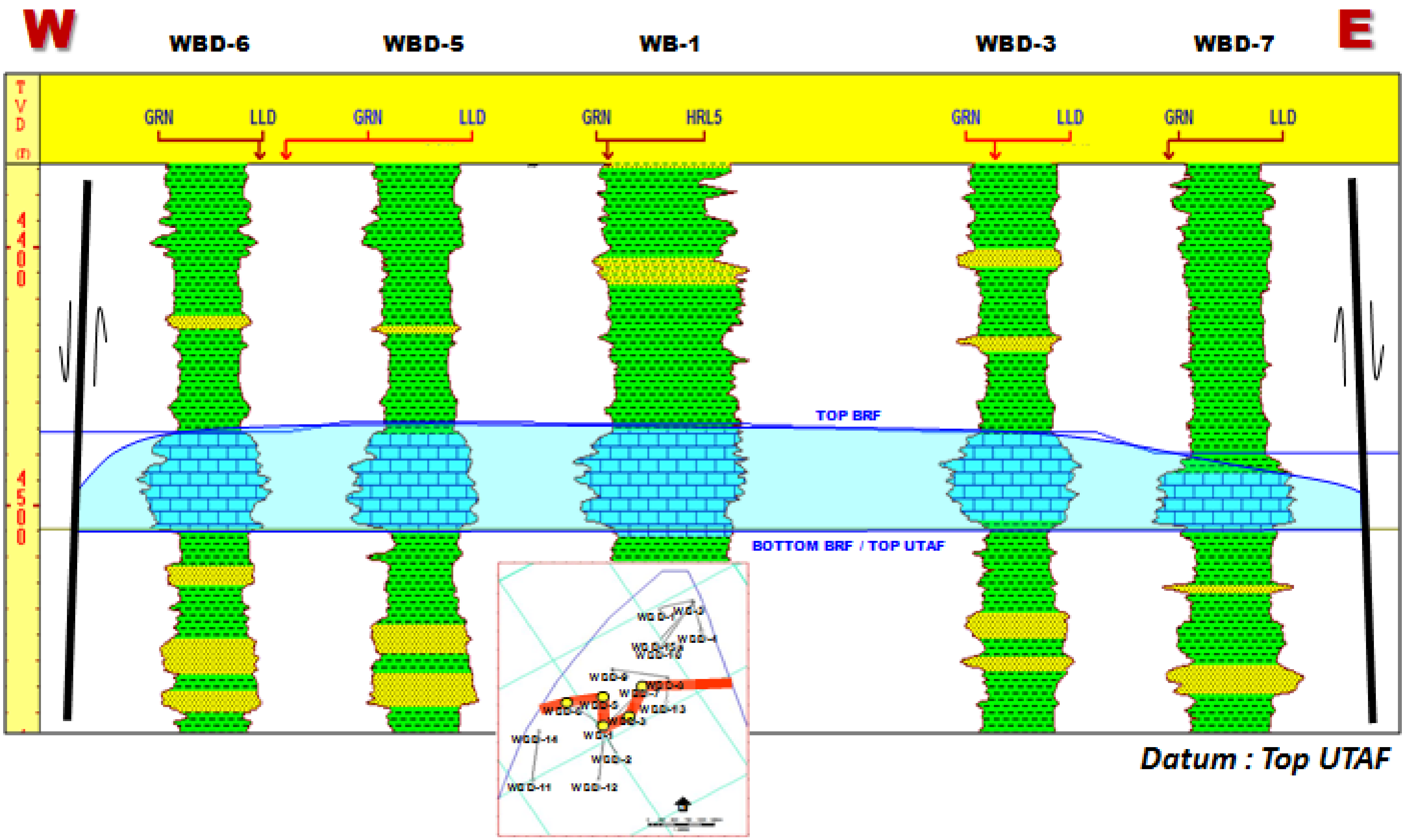

Figure 4. A local cross section of the Batu Raja formation in West Betara field based on well data.

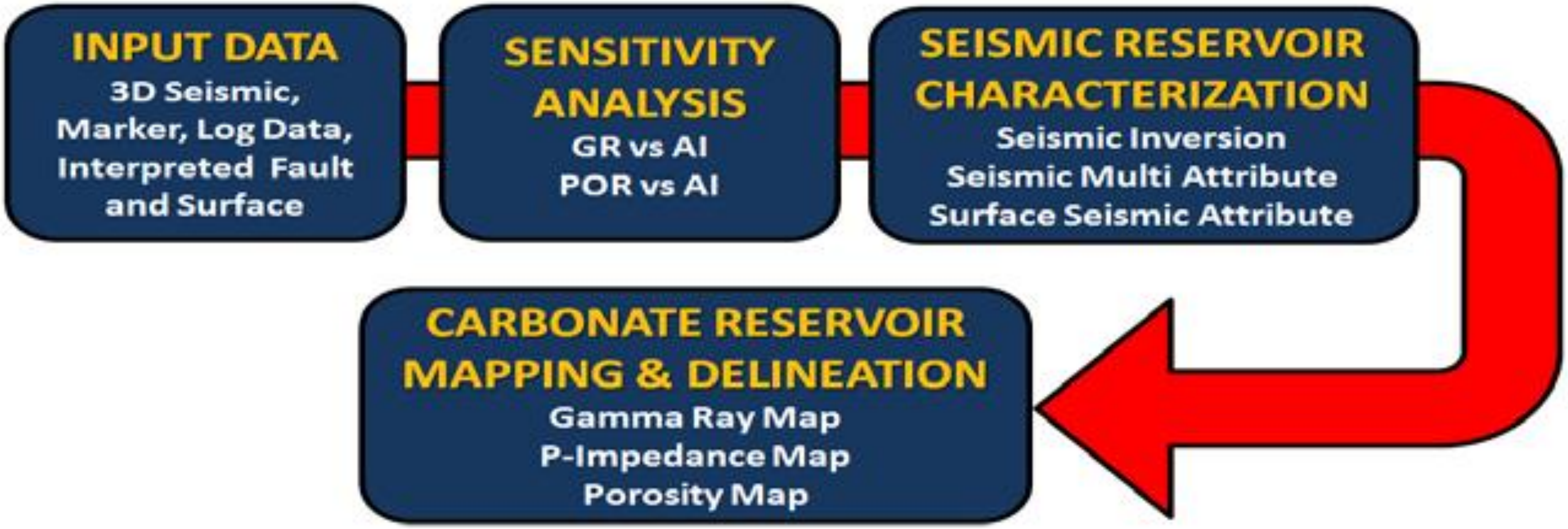

Figure 5. General Workflow of the study.

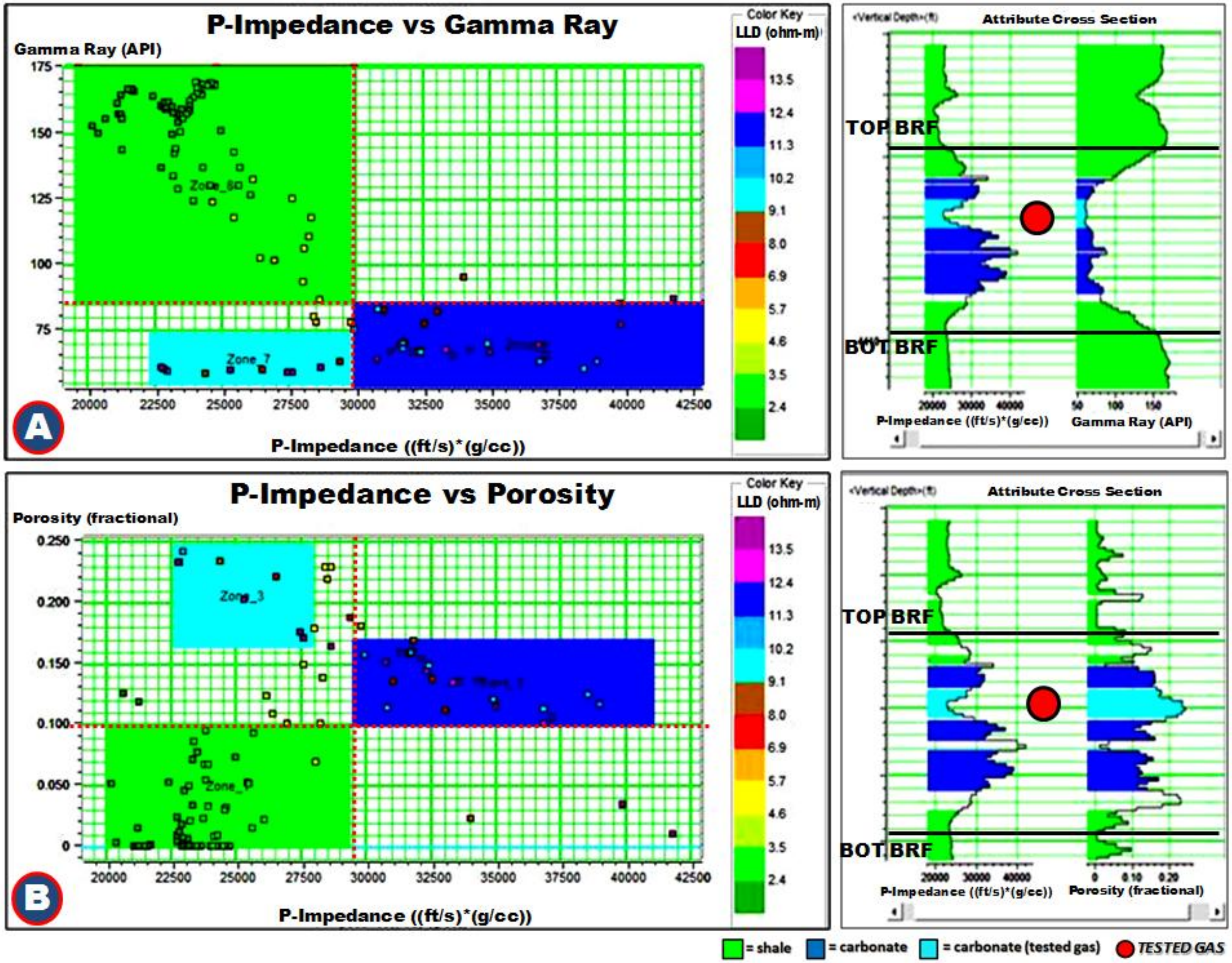

Figure 6. The sensitivity analysis example from WBD-8 log data by using log Gamma Ray, Porosity, P-Impedance and Resistivity. (A) The sensitivity analysis of Gamma Ray vs P-Impedance with color index Resistivity. (B) The sensitivity analysis of Porosity vs P-Impedance with color index Resistivity.

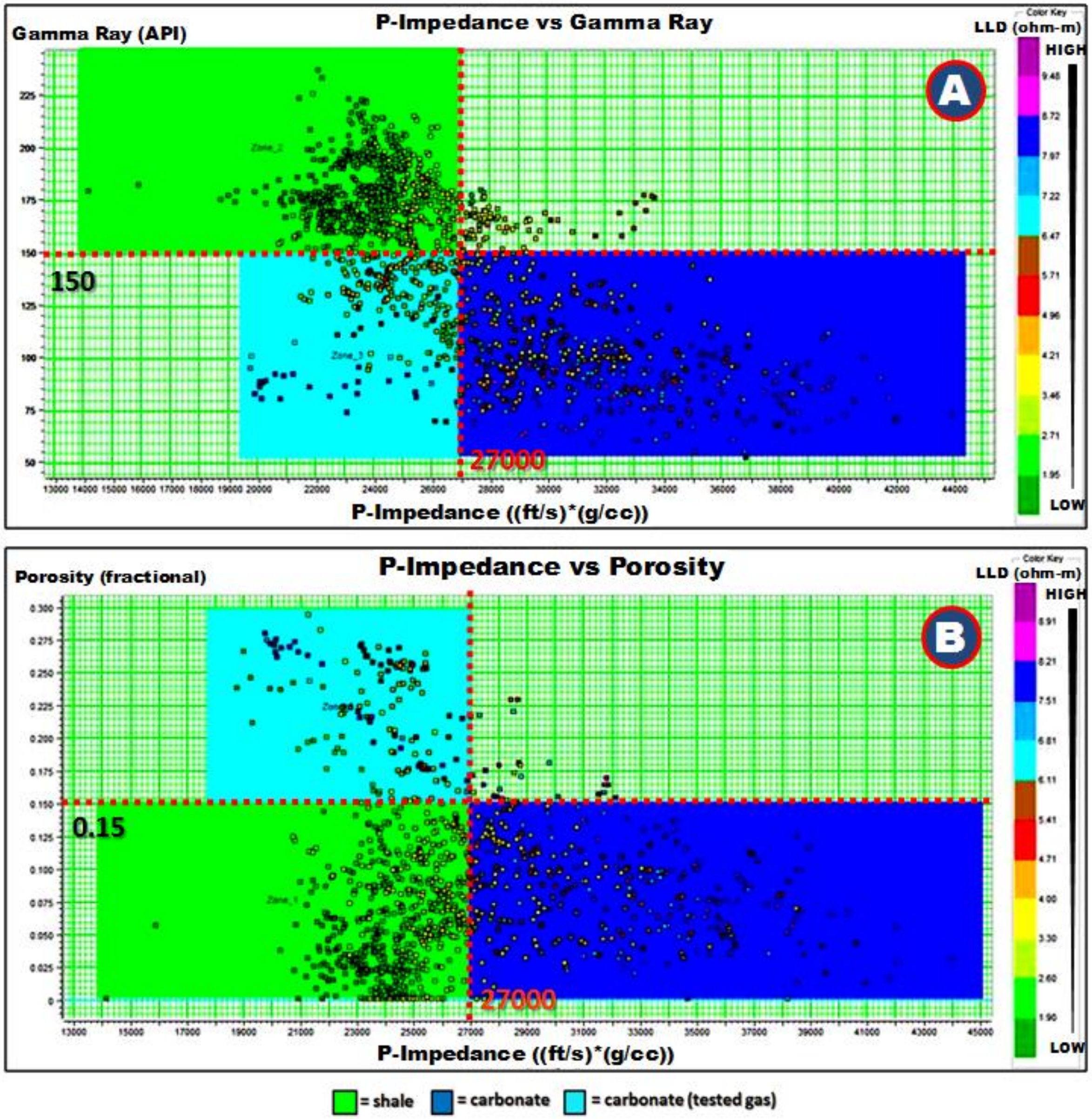

Figure 7. The sensitivity analysis applied for all existing wells of WB field. (A) The sensitivity analysis of Gamma Ray vs P-Impedance with color index Resistivity. (B) The sensitivity analysis of Porosity vs P-Impedance with color index Resistivity. Based on Log data, carbonate reservoir parameter is low Gamma Ray (range 50-150 API), low P-Impedance (range 18000-44000 (ft/s)*(gr/cc)) where low P-Impedance with range 18000-27000 (ft/s)*(gr/cc) is carbonate reservoir with gas content (A) and high Porosity with range 0.15-0.3 (fractional) (B).

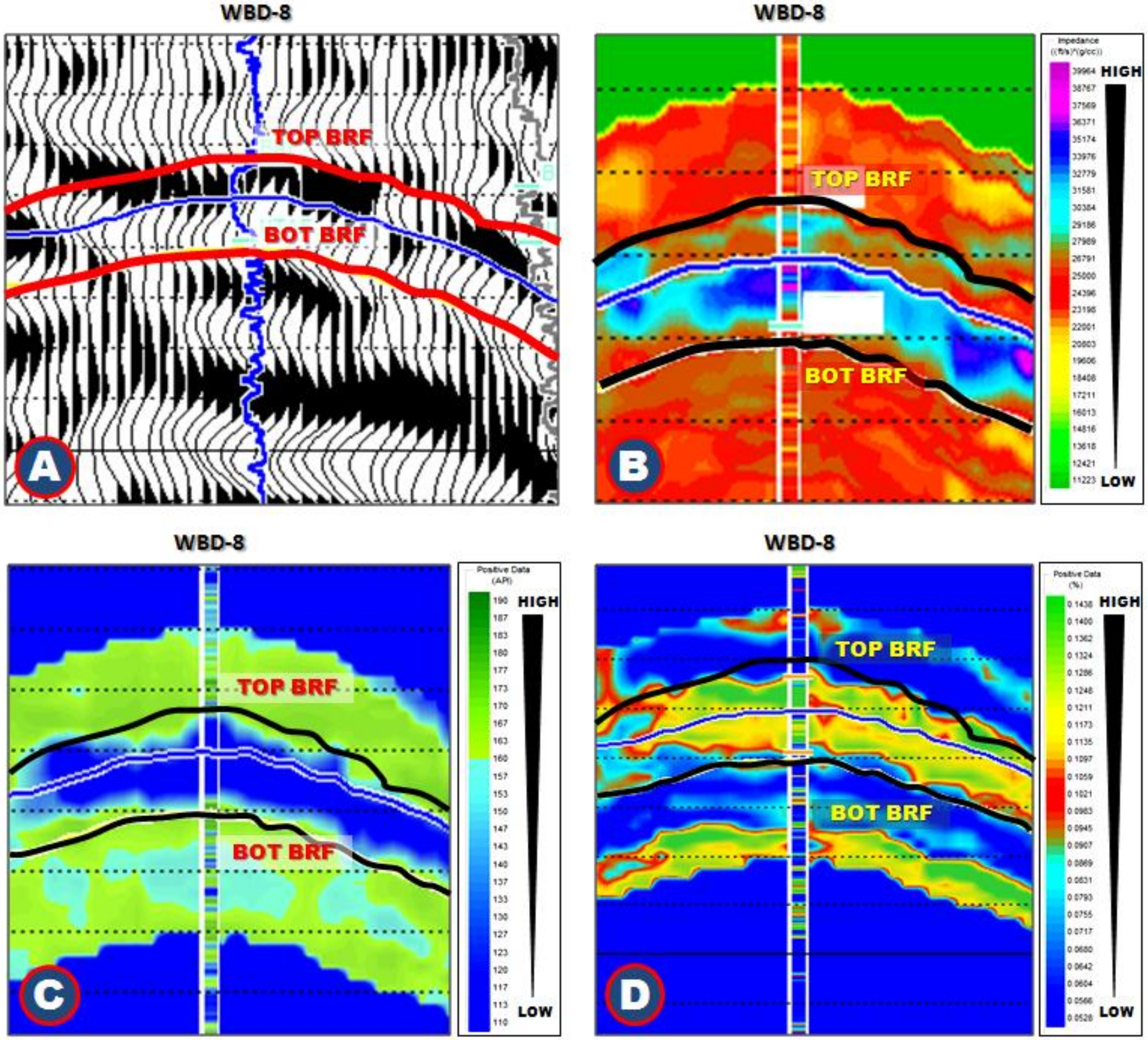

Figure 8. Original Seismic and Seismic Reservoir Characterization volume result with well control. (A) Original Seismic PSTM 3D with WBD-8 Gamma Ray log. (B) P-Impedance Volume with WBD-8 P-Impedance log. (C) Gamma Ray Volume with WBD-8 Gamma Ray log. (B) Porosity Volume with WBD-8 Porosity log.

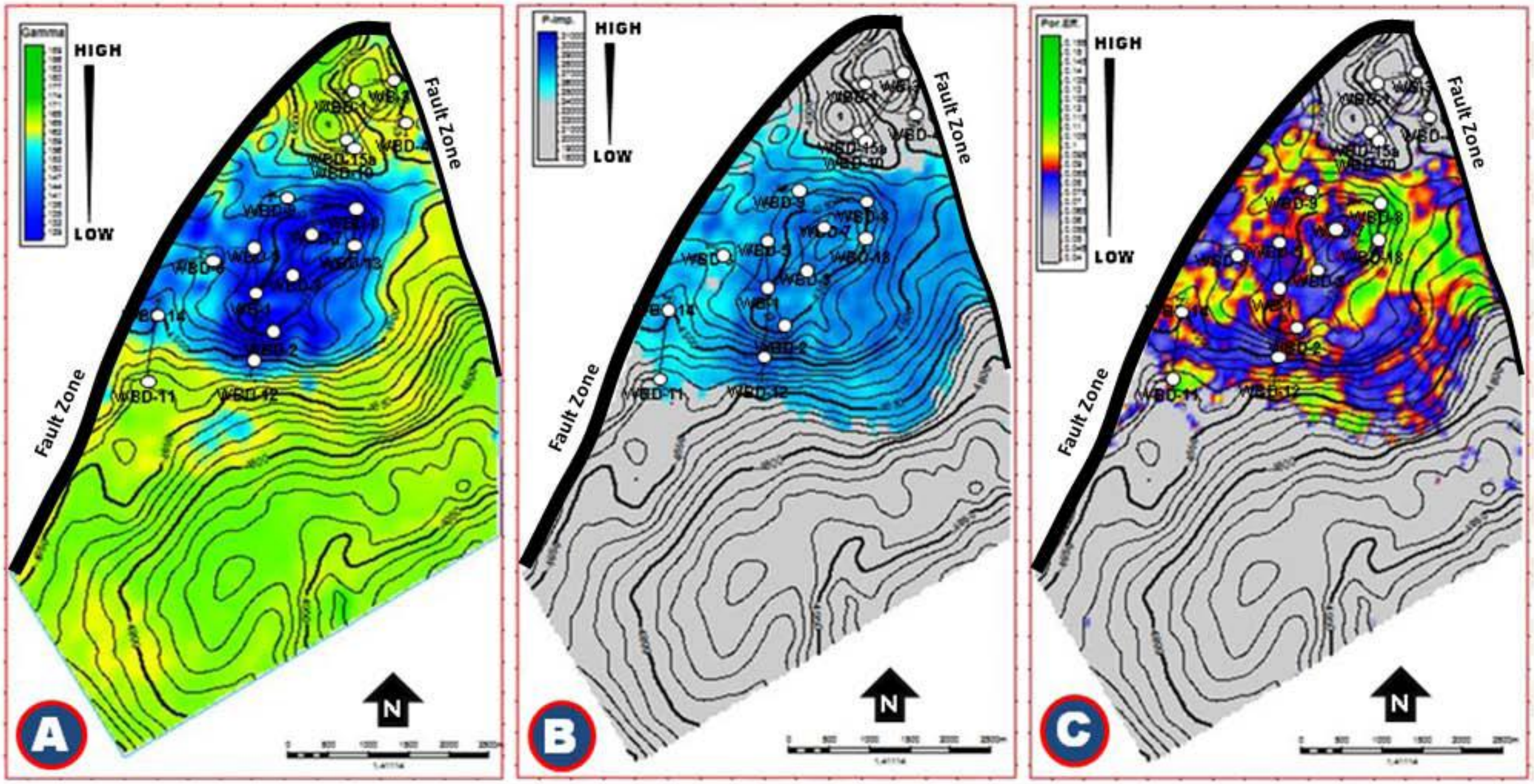

Figure 9. The lateral distribution of Batu Raja carbonate reservoir. (A) Gamma Ray Map with low value showing carboante facies boundary. (B) P-Impedance Map with high value showing carboante facies boundary. (C) Porosity Map showing porosity distribution and fit with facies boundary where carbonate with gas content has higher porosity value (red to green color) than carbonate reservoir with no gas content (red to dark blue color).

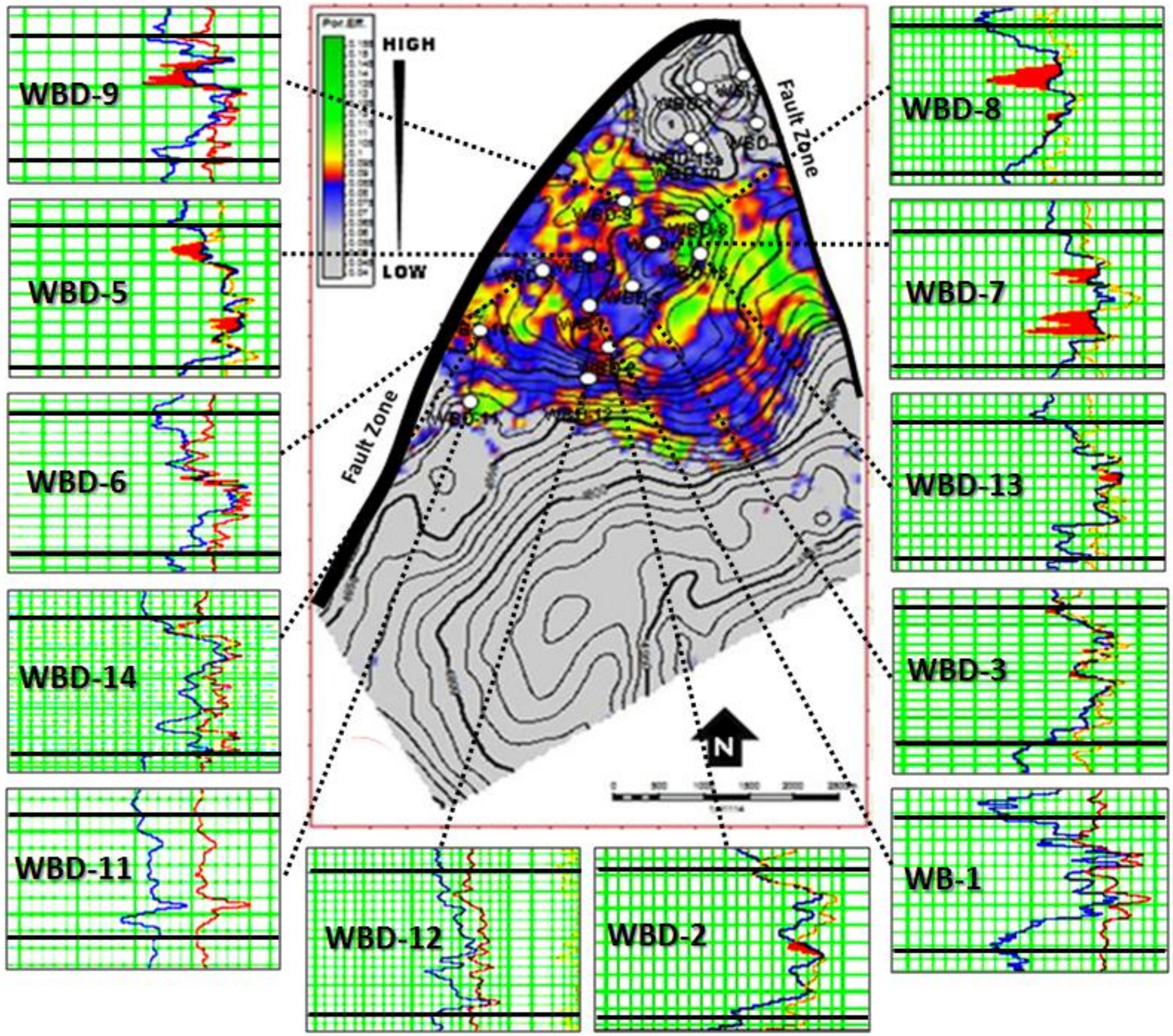

Figure 10. The comparison between Porosity Map and Existing log data. Good correlation shows that the Porosity Map and density-neutron log data in Batu Raja interval has a fairly relationship, where carbonate with gas content and carbonate reservoir with no gas content are distinguishable.