IOP Conf. Series: Earth and Environmental Science **132** (2018) 012010 doi:10.1088/1755-1315/132/1/012010

Acoustic Impedance Inversion To Identify Oligo-Miocene Carbonate Facies As Reservoir At Kangean Offshore Area

Arif Zuli Purnama[1,a], Pritta Ariyani Machmud[1], Budi Eka Nurcahya[1], Miftahul Yusro[2], Agung Gunawan[2], Dicky Rahmadi[2]

[1] Universitas Gadjah Mada, Yogyakarta, 55281, Indonesia
[2] SKK Migas, Jakarta, 12710, Indonesia

[a] arif_zuli@mail.ugm.ac.id

Abstract. Model based inversion was applied to inversion process of 2D seismic data in Kangean Offshore Area. Integration acoustic impedance from wells and seismic data was expected showing physical property, facies separation and reservoir quality of carbonate rock, particularly in Kangean Offshore Area. Quantitative and qualitative analysis has been conducted on the inversion results to characterize the carbonate reservoir part of Kujung and correlate it to depositional facies type. Main target exploration in Kangean Offshore Area is Kujung Formation (Oligo-Miocene Carbonate). The type of reservoir in this area generate from reef growing on the platform. Carbonate rock is a reservoir which has various type and scale of porosity. Facies determination is required to to predict reservoir quality, because each facies has its own porosity value. Acoustic impedance is used to identify and characterize Kujung carbonate facies, also could be used to predict the distribution of porosity. Low acoustic impedance correlated with packstone facies that has acoustic impedance value below 7400 gr/cc*m/s. In other situation, high acoustic impedance characterized by wackestone facies above 7400 gr/cc*m/s. The interpretation result indicated that Kujung carbonate rock dominated by packstone facies in the upper part of build-up and it has ideal porosity for hydrocarbon reservoir.

1. Introduction

In general, there are three main steps of seismic exploration method used to find hydrocarbon reserves i.e. acquisition, processing, and interpretation of seismic data. Seismic interpretation is used to determine and predict geological phenomenon from seismic data generated from processing (Sheriff and Geldart, 1995). Seismic interpretation has many types, one of them is reservoir characterization. Reservoir characterization is a process combining all existing data to define reservoir geometry and physical parameter distribution of hydrocarbon reservoir. The result of reservoir characterization is expected to generate subsurface model.

One method used frequently to define subsurface image is acoustic impedance seismic inversion. This inversion is applied to convert seismic wiggle into acoustic impedance value. Acoustic impedance is physical rock property having relation with porosity, density, even the thickness of reservoir rock target. Acoustic impedance inversion is divided into three types, one of them is model based acoustic impedance inversion. Model based generates subsurface model more accurate than the other type.

Kangean offshore was selected as study area. In general, carbonate rock reservoir has varies type and scale of porosity. Its porosity is highly related to facies type. So that in this study, model based acoustic impedance inversion defined physical property of rock is expected to separate varying types of facies from carbonate rock reservoir (Kujung Limestone).This is the reason that model based is selected in this study area.

2. Location and geology of study area

The study area is located in offshore area ± 50 km west from Kangean Island, this is within the Northeast Java Basins. Figure-1 shows the study area marked by Green polygon.

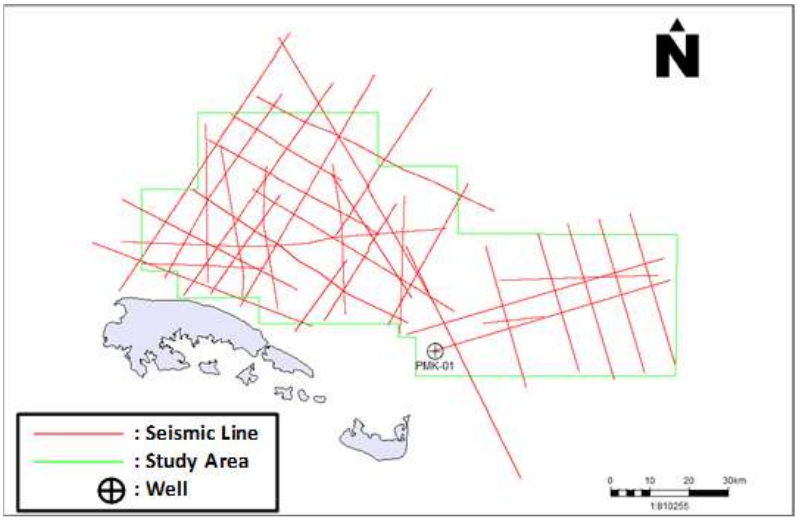

Figure 1. Base map of study area

The study area is controlled by one major fault, which is RMKS fault (Rembang-Madura-Kangean-Sakala). RMKS fault zone has wide in between 15 km to 40 km and length about 675 km from Rembang area on west to Tuban area on east, until Kangean Islands on the east of Madura Island. Inversion structure could be seen in this zone as a result of horizontal fault deformation i.e. folding, thrust fault. Depending on the diversity of its structure, RMKS fault zone is divided into three parts i.e. west region, center region, and east region (Satyana et al., 2004). The study area is included the east region of RMKS fault zone. It covered from Kangean islands to Flores sea area. The exposed rock on Kangean Island is older than Maduras rock, it proved the effect of RMKS fault in its zone that was bigger than Madura and Rembang zone (Satyana et al., 2004). RMKS fault inverted Paleogene basin formed by normal faults trending west-east. The structure of RMKS fault is shown by Figure-2. This figure shows Sepanjang in the south and Sakala in the north controlling the study area.

Mudjiono and Pireno (2001) divided the Northeast Java Basins into two parts i.e. offshore and onshore East Java/Madura, in addition they defined several sedimentary cycle i.e. Ngimbang, Kujung, Tuban and Ngrayong, Wonocolo, and Kawengan and Lidah cycle. This is shown by Figure-3. The oldest sediment is Pra-Ngimbang formation, this is terrestrial clastic sediment consisting sandstone, claystone, and intercalation of coal. Pra-Ngimbang formation was deposited in graben area at Pra-Tersier to Early Tersier by lacustrine and deltaic environment, so that this can be source rock of Northeast Java Basins. Ngimbang formation was deposited at Ngimbang Cycle (Eocene), It had half grabben filled by syn-rift sediment dominated by thick claystone. Kujung Formation is divided into three parts i.e. Kujung Limestone dominated by reef build-up, Kujung Shale dominated by limy shale and thin carbonate, Kujung Sandstone dominated by clastic sediment. Kujung Limestone Formation was believed as ideal hydrocarbon reservoir. The various facies of Kujung Limestone enable to stored hydrocarbon. Tuban Formation, in the study area, is dominated by shale. It is a massif sediment, unstructured, rich of green shale and foraminifera plankton. Tuban Formation could be caprock of Kujung Limestone reservoir.

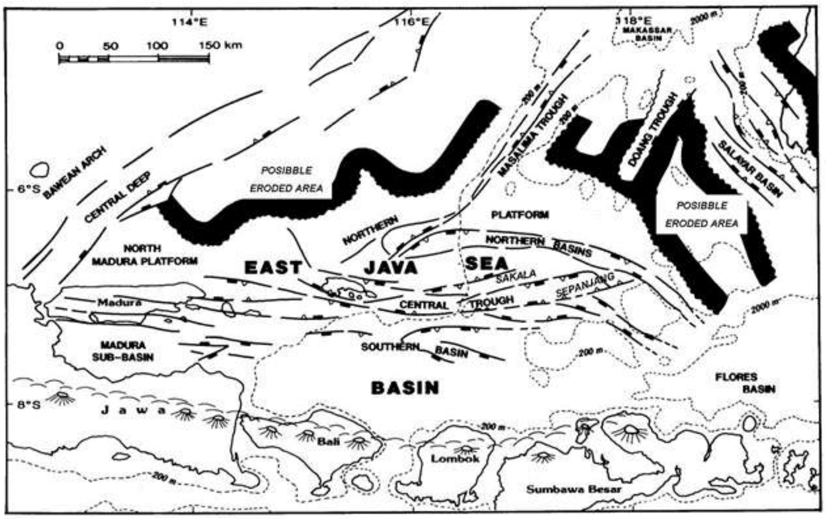

Figure 2. Tectonic structure of eastern region of RMKS fault zone (Bransden and Matthews., 1992)

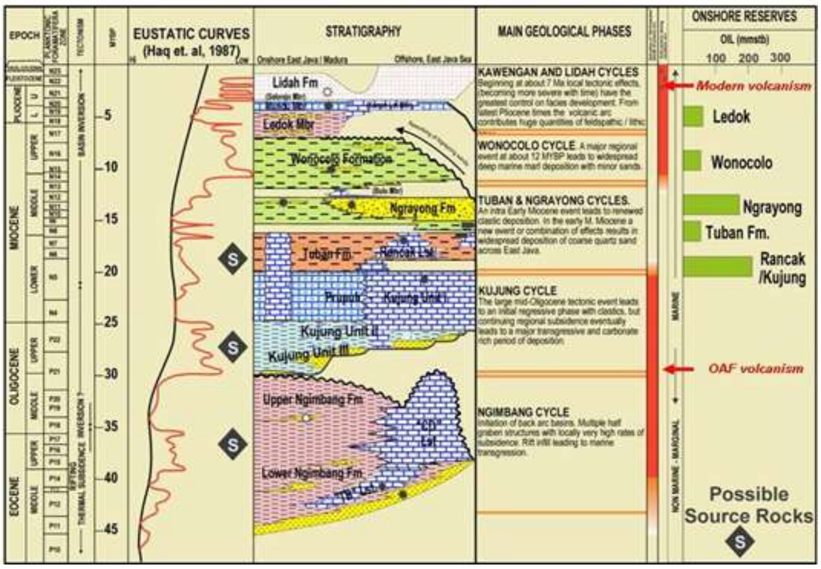

Figure 3. Stratigraphy and petroleum system of Northeast Java Basins (modify of Mudjiono and Pireno., 2001)

3. Theoretical background

Acoustic impedance is defined as the rock capability allowed seismic wave traveling through it. Physically, acoustic impedance is the product between medium density with seismic wave velocity (equation-1).

$$Z_i = \rho_i . V_i \quad (1)$$

where is the acoustic impedance in i medium, is i medium density, and is seismic wave velocity in i medium.

Acoustic impedance is the rock property related to lithology, porosity, fluid content, depth, pressure, and temperature. This means that acoustic impedance is not surface property of two rock layers but it is rock property. Antsey, in Sukmono (2000), determined the relation between hardness of rock with acoustic impedance. The harder rock will be more easily traveled by acoustic wave than the softer one.

Seismic inversion is a technique to generate subsurface model using seismic data as an input and well data as a control (sukmono, 2000). Based on the definition, seismic inversion is an reverse technique from forward modeling. The result of seismic inversion is synthetic seismic section based on earth model.

In order to get maximum result, seismic inversion is applied only to the post-stack seismic data and acoustic impedance is extracted from well data. Acoustic impedance is the product between density with velocity log of well data. It gives high quality vertical resolution but low quality in lateral. Otherwise, acoustic impedance seismic gives high quality lateral resolution but low in vertical. So that, the integration between seismic and well will generate an effective and efficient way to characterize reservoir.

Model based inversion is a type of seismic inversion generating blocky acoustic impedance model from well data. The first step of model based inversion is building an acoustic impedance model. Then wavelet convolution will be applied on thus model. The result of convolution is synthetic seismic that will be compared to the original seismic data. The comparison of the model (convolution result) with the original seismic using iteration will be ended when it has small error value. In order to get the smallest error value, the model must be updated continuously. Updating the model is used generalized linear inversion method. This is a method using the most suitable acoustic model derivative to the original seismic data, it called Marquardt-Levenburg method (Russell, 1996). Model based inversion is based on convolution model shown by equation-2.

$$seismic = wavelet * reflectivity + noise \tag{2}$$

With the assumption that seismic trace and wavelet have been known, also the noise is not interconnected and random. Model based inversion is blocky model, it consists of small blocks representing inversion image resolution. The smaller the block, the longer inversion process, but the higher resolution will be obtained. With the high resolution of seismic data, it is highly useful for accurately interpretation (chopra et al., 2006).

4. Results and discussion

The data given in this study area are 35 seismic lines and a PMK-01 well. The base map of study area including seismic and well data is shown by Figure-1. Acoustic impedance inversion was applied to seismic data controlled by well. This is expected to determine characteristics of target reservoir. The target reservoir is Oligo-Miocene carbonate rock called as Kujung Limestone, its facies become characteristics determined by acoustic impedance inversion. The inversion is processed from time -100ms Kujung Limestone to +100ms Ngimbang Horizon.

PMK-01 well is located at deep marine, then it became high area as the result of RMKS inversion. Sedimentation supply came from Lombok High, so that Lombok Ridge highly affected its sedimentation. The Oligo-Miocene carbonate rock in this well is dominated by wackestone in the lower part, marl in the middle part, and interbedded of marl and packstone in the upper part. The existence of marl and wackestone is caused by Fore Reef environment. Fore Reef is characterized by lithology i.e. shale, skeletal wackestone, mudstone, marl, rudstone/floatstone, and dolomite (mixing zone) (Hadnford and Loucks .,1993).

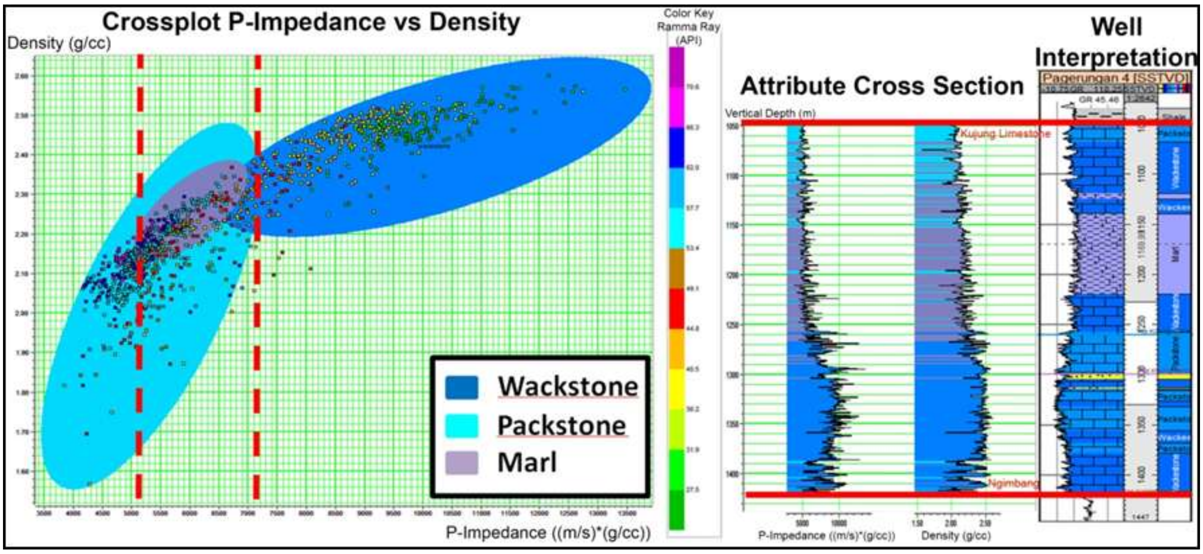

Figure 4. Crossplot analysis of PMK-01 Well

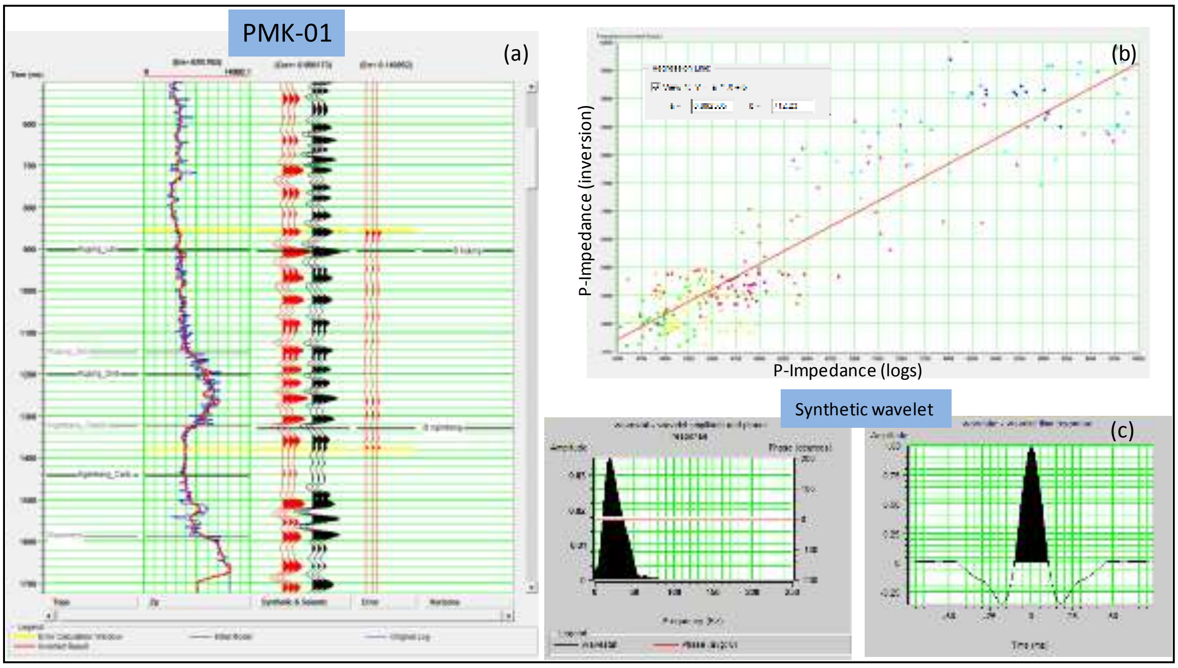

Figure 5. The inversion parameter i.e. (a) comparison log, (b) crossplot acoustic impedance log between inversion result and original log, (c) the inversion wavelet.

The crossplot analysis is conducted as the first step in acoustic impedance inversion. The crossplot analysis is shown by Figure-4, it describes the relation of acoustic impedance to density with gamma ray color key within Kujung Limestone. Kujung Limestone is divided into three facies with various acoustic impedance values. There are two cut off value of acoustic impedance separating its facies i.e. 5200 gr/cc*m/s for packstone-marl and 7400 gr/cc*m/s for marl-wackestone. Interbedded of wackestone and packstone (well interpretation) was hard to defined by acoustic impedance, it possibly is caused by thin section of packstone-wackestone. It is smaller than minimum range of crossplot picked data, so that acoustic impedance does not separate packstone-wackestone interbedded.

The tying technique between seismic data to well log called as well to seismic tie is the first process of inversion. Well to seismic tie correlates seismic data (time domain) to the well log (depth domain). It is used synthetic seismogram generated by velocity survey. Velocity survey is convolution process from wavelet and coefficient reflection. Coefficient reflection is the product of sonic and density log from the well data, it also represented acoustic impedance log.

Inversion analysis was conducted to define the best parameter for inversion. It compares the initial model (product of applying acoustic impedance log to seismic) to initial log. This method is shown by Figure-5. The comparison between initial log (blue), initial model (black), and inversion result (red) shown by Figure-5 (a) has 0.99 correlation value and 0.14 of error. Inversion analysis was applied to the target area which is Oligo-Miocene carbonate rock called Kujung Limestone, so that the correlation and error value were calculated from Kujung to Ngimbang. The synthetic seismogram is identically the same as seismic data. It describes that inversion result will be the same relatively as acoustic impedance log generated before. Figure-5(b) shows the crossplot of acoustic impedance log from inversion result and original log. The distribution of log data have linear relation, it describes the similarity of inversion result to original log. Figure-5(c) shows the wavelet generated by statistically calculation from seismic. It is the same used in the well to seismic tie process.

There are two horizons picked in this study which are Top Kujung Limestone and Top Ngimbang (as Base Kujung). Interpretation of thus horizons was controlled by marker data from well and seismic stratigraphy. Build-up form is located below Tuban-Kujung unconformity. It has different composition of seismic amplitude than the other surrounding it. It means the lithology within build-up also different. Meanwhile Ngimbang was picked by the continuity from well marker to seismic.

The seismic interpretation is shown by Figure-6 (a). The result of acoustic impedance inversion is shown by Figure-6 (b). The acoustic impedance inversion could separate carbonate facies, but not for thin interbedded facies. Thin interbedded of wackestone-packestone in the lower part became fully wackstone facies. Also thin interbedded of wackestone-packstone in the upper part became packstone facies with thin marl within it. In the other hand, wackestone facies is represented by blue-purple color, it is above 7400 gr/cc*m/s acoustic impedance value. Packstone facies is represented by cyan-green color having below 7400 gr/cc*m/s acoustic impedance value.

Oligo-Miocene carbonate build-up in this study was the result of fore reef environment. It made wackstone and marl dominating its build-up. The few amount of packstone in the upper part of build-up was the result of changing environment to reef core. The good reservoir is marked by packstone facies in the upper part of build-up Kujung Limestone represented by light green color of acoustic impedance.

Figure-7 shows acoustic impedance map overlay with Kujung Limestone time structure map. It explains the dominant facies of the study area which is packstone facies. On the southern part of the study area has build-up with dominant wackestone facies. This build-up possibly was formed in the lower area, so that wackestone facies grew perfectly. On the northern part of the study area has build-up with dominant packstone facies. It possibly was formed in the platform area with steady position of Kujung Limestone.

The prospect area for the next development of oil and gas exploration is northern part of the study area. It has low acoustic impedance indicating packstone facies and goo porosity. It las so has build-up in the several location with constantly the thickness of Kujung Limestone.

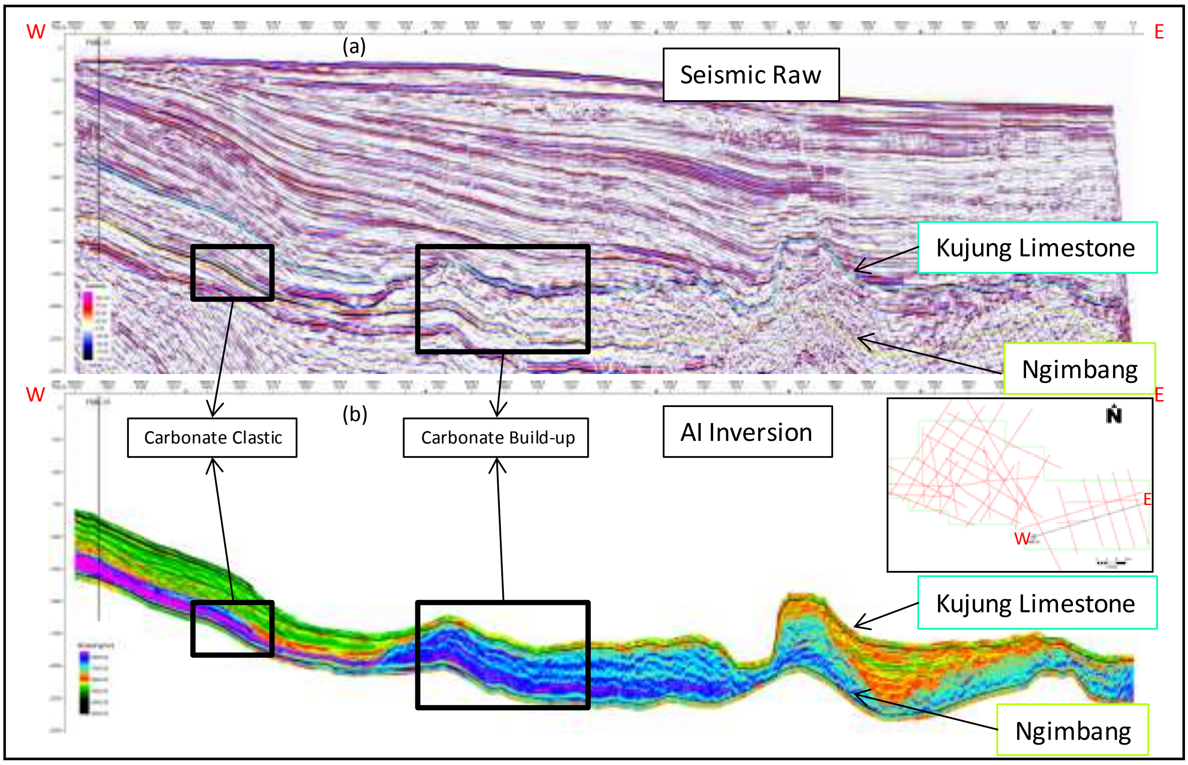

Figure 6. The section of (a) seismic interpretation and (b) inversion result.

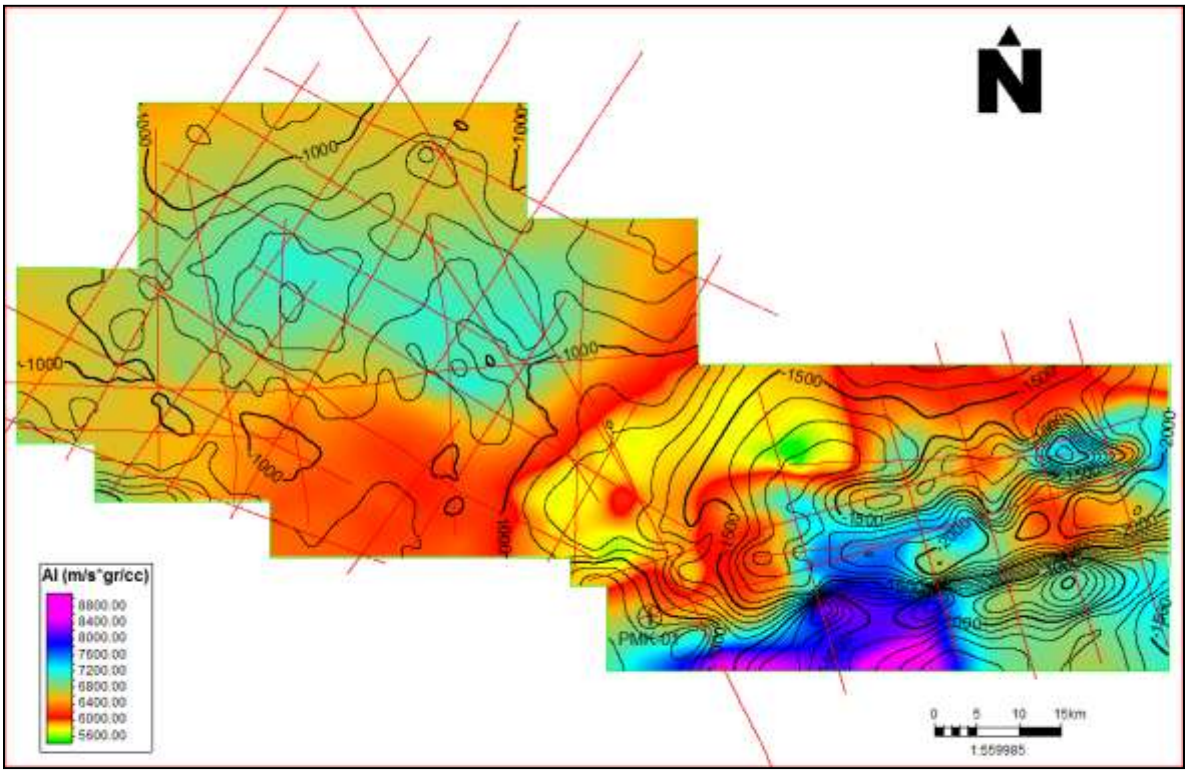

Figure 7. The accoustic impedance map overlay Kujung Limestone time structure map.

5. Conclusion

Based on well log sensitivity test, Oligo-miocene carbonate facies of Kujung can be well separated by it's acoustic impedance and density value. Packstone has low acoustic impedance below 7400 gr/cc*m/s, meanwhile wackestone has higher acoustic impedance. Acoustic impedance inversion was done using a model based method. Oligo-miocene carbonates of Kujung built up are dominated by wackestone and marl facies, where the packstone facies is found at the top of built up. This built-up succession shows the deposition environment of the fore reef. The acoustic impedance map overlaid by structural maps provides an overview of the built-up and clastic carbonate distribution, where built up carbonates are found in the northern and southern areas. The northern area was found abundant of good porosity packstone, while the southern part was abundant of poor porosity wackestone. This corresponds to the regional geology of fore reef in study area, where the northern part was on the platform environment while the southern part was deeper. The northern area are a potential area for hydrocarbon reservoir.

References

[1] Chopra, S., Castagna, J., Portniauguine, O., 2006.Seismic resolution and thin-bed reflectivity inversion.CSEG Recorder.
[2] Handford, C. R., and R. G. Loucks, 1993. Carbonate depositional sequences and systems tracts-responses of carbonate platforms to relative sea-level change. Recent Advances and Applications: American Association of Petroleum Geologists Memoir 57, p. 3-41.
[3] Mudjiono, R., and Pireno, G. E., 2006.Exploration of the North Madura Platform, Offshore East Java, Indonesia.Proceeding of IPA Convention and Exhibition.
[4] Russell, B. H., 1996. Strata Workshop.Hampson-Russell Software Services Ltd.
[5] Satyana, A. H., 2014, New Consideration on the Cretaceous Subduction Zone of Ciletuh LukUlo – Bayat – Meratus: Implications for Southeast Sundaland Petroleum Geology. Proceeding of IPA Convention and Exhibition.
[6] Sheriff, R.E. andGeldart, L.P., 1995.Exploration Seismology. Cambridge University Press, Second Edition.
[7] Sukmono, S., 2000.Seismic Inversion for Reservoir Characterization. Laboratorium Teknik Geofisika, TeknikGeofisika ITB, Bandung.
[8] Wisatria, B., 2009. Hydrocarbon Prospect Zone Determination Using Attribute Analysis and Seismic Inversion of "INDAH" Field.Geophysics Laboratory, Physics Department, Mathematic and Natural Science Faculty, UniversitasGadjahMada, Yogyakarta.

Acknowledgments

This study initiated by SKK Migas cooperated with UPN Veteran Yogyakarta, Universitas Gadjah Mada and several PSC developing East Java Basins. This study became motivation and example for geoscientists and practitioners of oil and gas industry to keep spirit doing research and exploration in the effort of national oil and gas resources and production enhancement. Thanks to Deputy for Planning Management Chief and Exploration Division Chief of SKK Migas for the support, also all of the PSC helping the realization of this study. Also we thank to UPP university partnership program Chevron-UGM for supporting hardware and software facility.