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RESEARCH ARTICLE

Characterization of hydrocarbon reservoir at field "B", South Sumatera by using poisson impedance inversion

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Abstract

The separation process of lithology and fluid reservoir is an important part in the characterization of reservoir. It will explain the physical properties of reservoir rock lithology and fluid content by integrating the geophysics and petrophysical data. This process is difficult to do in the field "B" by using parameters of acoustic impedance and lambda mu rho (LMR), because it still has a fairly high degree of ambiguity. Poisson impedance (PI) has been implemented as a solution to address the problem. In cross-plot between Acoustic Impedance (AI) and Shear Impedance (SI), a rotation of both axes was conducted according to the trend of lithology-fluid to satisfy the equation of PI = AI – *c*SI. To improve the accuracy of PI calculation, the value of *c* (optimization factor of rotation) was calculated through the method of TCCA (Target Correlation Coefficient Analysis). The correlation with to be predicted wells data then be done. Analysis of sensitivity parameter was performed on two wells in the field "B". Parameters Zp, Zs and density which obtained from the simultaneous inversion then transformed into PI. PI models clearly showed the separation of rock lithology of hydrocarbon reservoir. Lithology impedance (LI) as a result of the PI-GR correlation was able to separate sand and shale very well. Similarly, the impedance Fluid (FI) as a result of PI-SW correlation was also able to separate the water content in the reservoir with high SW value relative to gas with a low value of SW. Hydrocarbon zone proven at 2360-2400 m. The slicing result of the volumes of Poisson impedance inversion has provided a clearly distribution and interpretation of lithology and fluid content reservoir at the field "B" of South Sumatera.

Keywords: Reservoir characterization; Poisson impedance; TCCA; lithology; South Sumatra

INTRODUCTION

Reservoir characterization is an attempt to describe the physical properties of rock (Hampson & Russell, 2011) and fluid content of reservoir by integrating the geophysical and petrophysical data. Lithology that associated with its rock types is sandstone or carbonate contained in hydrocarbon reservoirs. Similarly, the fluid content will provide an overview of the reservoir, in which fluid may be water, gas or oil. It becomes important for reservoir characterization to provide a description of hydrocarbon exploration that will be further developed into the exploitation phase or not.

One of methods to characterize the reservoir is the inversion method. Seismic inversion is one of the most widely used methods in the exploration of hydrocarbons. This method is a way to create a model of the subsurface with seismic data as input and well log as controls. There are several methods of seismic inversion; one of the most former inversions is *AI* (Acoustic Impedance inversion). *AI* is a seismic parameter which value is affected by porosity, lithology, and fluid type contained in rocks. However, it turns out that acoustic impedance parameter alone is not enough to predict the properties of porosity and fluid content due to the separation between lithology (sandstone/shale) and fluid content that is still overlapped and cannot be separated properly, resulting *AI* to has ambiguity.

Combination of acoustic and shear impedance (*AI-SI*) parameters forms a new single attribute that is an attribute Poisson impedance (PI). This attribute is a solution to address the difficulty in separating lithology-fluid distribution in the *x*-axis and *y*-axis on crossplot between Acoustic Impedance (*AI*) and Shear Impedance (*SI*) (Mark *et al.*, 2006).

Simultaneous Inversion method is other seismic inversion method that is newly developed. This method uses a pre-stack seismic data as input to get output parameter and results are in the form of P-impedance inversion, S-impedance, and density. In making PI model, Poisson impedance inversion method is used to directly extract *AI* and *SI* by Simultaneous Inversion. It has been selected because it can produce more stable inversion and reduce ambiguity problems in seismic inversion (Hampson & Russell, 2011).

To increase the accuracy of calculation of Poisson impedance, *c* optimum value is calculated through the method of TCCA (Target Correlation Coefficient Analysis) (Tian *et al.*, 2010). Then, it will automatically calculate correlation coefficients between PI curve with *c* different values, and then will compare with the curve of Gamma Ray (GR) and the curve of water saturation (SW). The *c* value corresponding to the maximum correlation coefficient for GR is used to calculate the attributes that will emphasize known as impedance lithology and lithology (LI). Similarly, the impedance of the fluid (FI) is calculated using the value of *c* corresponding to the maximum correlation coefficient for water saturation curve (SW) (Direzza & Permana, 2012). In the near future, it is to be hoped that this PI research will give further information about distribution and interpretation lithology and fluid content on reservoir at field "B" that known as old well and upside potential.

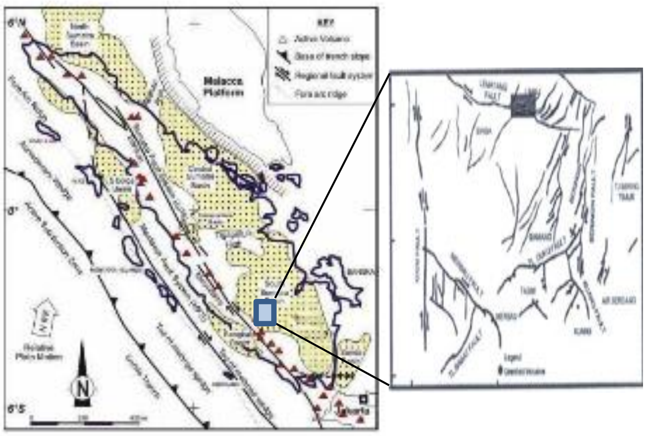
LITERATURE REVIEW

Regional geology

South Sumatra Basin, as shown in Fig. 1 (a) is situated by Sunda Exposure to the Northeast, Lampung elevation area in the Southeast, Bukit Barisan Mountains to the Southwest and the Dua Belas Mountains and the Tiga Puluh Mountains to the Northwest.

Field "B" is located about 20–30 km to the West of Prabumulih. Geologically, it lies in Limau Graben and is an anticlinorium track: Pendopo, Benuang, Prabumulih Barat, Talang Jimar up to Ogan. The field structure "B" is an asymmetric fault-bend fold trap from the Lematang Fault that has an almost East-West strike. As a counterweight/release of compression force Lematang Fault, it is then formed a normal fault that has a pattern strike relative North-South as shown at Fig. 1 (b) (Syafrin & Erwinsyah, 2005).

Regional stratigraphy that is located in the basin of South Sumatra formed on several formations, generally sorted from old to young. The interest zone is Talang Akar Formation (TAF) with lithology of sand interbeded by shale and its age is late Oligocene to early Miocene.



(a) (b)

Fig. 1 (a) Basin map of Sumatera (from Bishop, 2001) and (b) structural map of field "B".

Poisson impedance

Poisson ratio and low densities values in the reservoir can usually use to indicate the presence of hydrocarbon. The points of data will be well separated if the lithology is clean sand. If the quality of sand is shaly sand or dirty sand, then the process of data separation becomes difficult. So, to face the situation, these two parameters can be combined into single attribute of Poisson impedance (PI) attribute. This attribute is one of the rock physics parameters that can be practically applied to predict the reservoir and detect the presence of hydrocarbons (Mark *et al.*, 2006). Poisson Impedance is a solution to the difficulty in separating the distribution of lithologies on the *x* and *y* axes on the crossplot between the Acoustic Impedance (*AI*) and Shear Impedance (*SI*). For the separation of the distribution to be obvious, both axes are rotated in following fluid-trending lithologies (Kevin, 2006) as shown in Fig. 2. The PI attribute is used as an indicator that requires input of *AI*, *SI* and *c* value (rotation optimization factor) obtained from the inverse of the slope to increase Poisson impedance calculation accuracy.

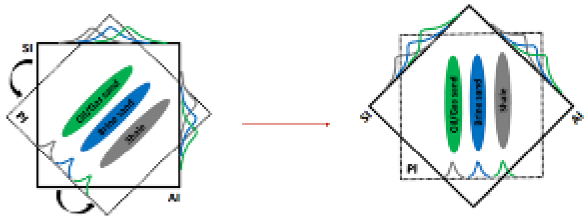


Fig. 2 Poisson Impedance which rotating the *AI*-*SI* axes (Mark *et al.*, 2006).

Mathematically the Poisson Impedance can be expressed by this formula (Mark *et al.*, 2006)

$$PI = AI - cSI \tag{1}$$

TCCA (Target coefficient correlation analysis)

This stage is to get the value of *c* that is best obtained from the correlation between PI log with log targets in each well. In this case, the Gamma Ray log is used to get *c* for lithology impedance and SW log for Fluid Impedance.

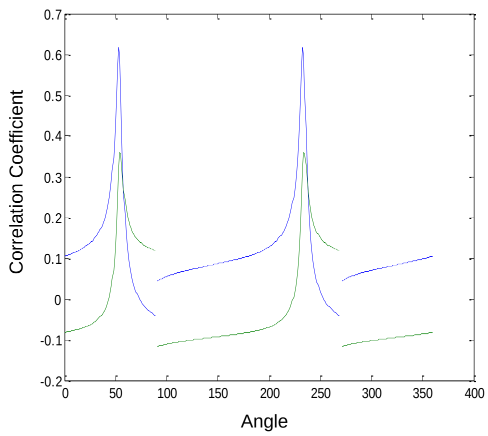


Fig. 3 Curve of PI vs GR above that indicated by the blue line correlations (*r*) of 0.6178, then draw a line down as the x-axis is PI(*c*) where *c* is entered in the form of 0-180° angle. We obtained the optimum angles of 53° and 54° then using equation form of tan Φ. Thereby, the optimizing rotation factors, *c*, used are 1.3270 and 1.3764, respectively for equation of lithology impedance and fluid impedance at wells 81.

Mathematically in geometry, PI is axis rotation *x* and *y* by Φ (Fig. 4). Transformation of axis rotation *x*-*y* in form of matrix rotation,

$$\begin{bmatrix} u \\ v \end{bmatrix} = \begin{bmatrix} cos\,\Phi & -\sin\Phi \\ sin\Phi & cos\Phi \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} \tag{2}$$

At new axis *u*-*v* show,

$$u = x\cos\Phi - y\sin\Phi \tag{3}$$

$$v = x\sin\Phi + \mathrm{y}\cos\Phi \tag{4}$$

and by the form of equation 3, substitute the axis with AI-SI, then:

$$PI = AI\cos\Phi - SI\sin\Phi \tag{5}$$

$$\frac{PI}{\cos\Phi} = AI - SI\tan\Phi \tag{6}$$

So, it can be shown c (rotation optimal factor) is

$$c = \frac{\sin\Phi}{\cos\Phi} = \tan\Phi \tag{7}$$

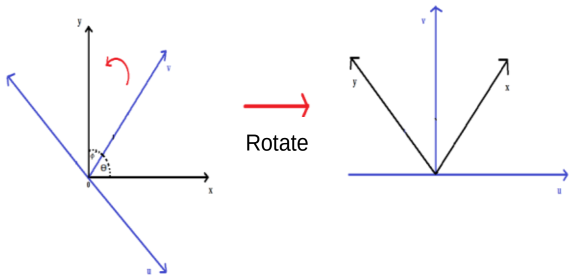


Fig. 4. Axis rotation, *x-y* axis is rotated and made a new axis that shown by *u-v* axis.

By implementing the simple theory above, Poisson impedance will be very useful for reservoir characterization in the near future because the more complexity of oil and gas exploration needs the simpler way to characterize.

METHODOLOGY

The study has been done by following several steps preparing the data to be processed, i.e. pre-stack and post-stack seismic data, well data research area, and regional geology.

- Crossplot analysis, i.e. by cross plotting well data.
- Wavelet extraction taken from post stack seismic data.
- Extracting data with seismic data (well to seismic tie).
- Choosing a horizon based marker on the well data.
- Conditioning pre-stack data from gathering data into angle gathering and angle-stack.
- Wavelet extraction taken from data angle stack for near-stack, mid-stack, and far-stack.
- Creating an initial model for acoustic impedance, shear impedance, and density.
- Analysis of results.
- Simultaneous inversion to generate acoustic impedance, shear impedance, and density.
- TCCA (Targeted Correlation Coefficient Analysis) to get the optimum c value.
- Poisson impedance transformation techniques in both rock's lithology and fluid content.
- Characterizing the reservoir.

RESULTS

There were some overlapping properties between sand and shale based on the value of *AI*, *SI*, *LR*, and *MR*. It can be seen from the crossplot of *AI* versus *SI*, and *LR* versus *MR* in Fig. 5. Therefore, Poisson impedance was later performed to help in solving this issue. As can be seen at (a), there were overlappings between shale which have high GR value (green) with a low sandstone GR-value (yellow).

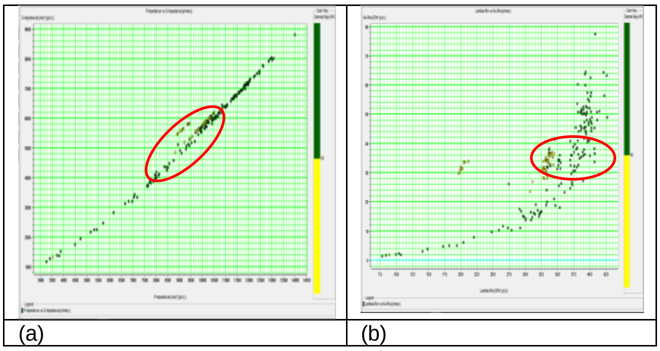


Fig. 5 *AI* versus *SI* crossplot in wells 81 (a) between P-wave impedance (*Zp*) and S-wave impedance (*Zs*) and (b) *LR* versus *MR*. Both of conditions use Gamma Ray value as a color scale.

Sandstone zones that are in *Zp* 8700-10500 (m/s) (g/cc) and *Zs* in 4700-6500 (m/s) (g/cc) will be used as a control in cross section to see the distribution of seismic inversion of suspected reservoir zone. It can be seen in Fig. 5b that the crossplot between Lambda-Rho and Mu-Rho at wells 81 with GR as color key, better than the parameters before, but not good enough to separate the lithological shale, which still occurs in overlapping zone of sandstone on the mu-rho range of 28-40 (GPa*g/cc).

Lithology impedance and fluid impedance at well

Crossplot of Poisson impedance versus Gamma Ray (shown in Fig. 6) called lithology impedance with c value of 1.327 provides a clear separation of reservoir lithology in the form of sandstone (yellow) and shale (dark green). In Fig. 7, Fluid Impedance (FI) was obtained by using c value of 1.376 which able to separate hydrocarbon from water. If the water saturation high, it can be ascertained that the zone contains water, and if the zone shows low value of water saturation, then the zone can be suspected as hydrocarbon zones or more specifically in the form of gas. By looking at both crossplots of PI-GR and PI-SW, the target interval could be interpreted as sandstone with oil/gas as fluid content. A better separation of lithology and fluid can be achieved by plotting Fluid Impedance (FI) with lambda-rho and Lithology Impedance (LI) with mu-rho. The water saturation high (dark blue) in Fig. 7 could be ascertained as the zone containing the high water. In the zone that indicated the value of water saturation is low, then that zone can be expected in the form of hydrocarbon zones or more specifically in the form of gas (light blue). By looking at both crossplots, PI and PI-GR-SW were allegedly reservoir sandstones form with the content of oil-gas.

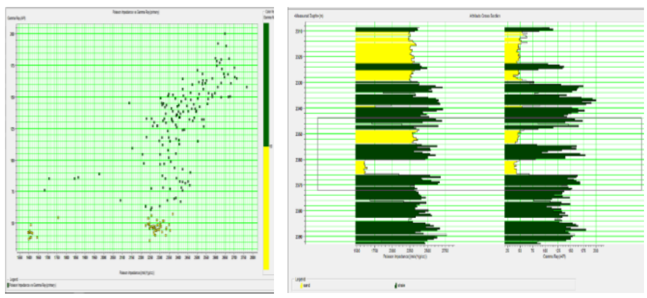


Fig. 6 Crossplot and cross section at well 81 of PI versus GR called lithology impedance with c (1.327) to provide a clear separation reservoir lithology in the form of sandstone (yellow) and shale (dark green).

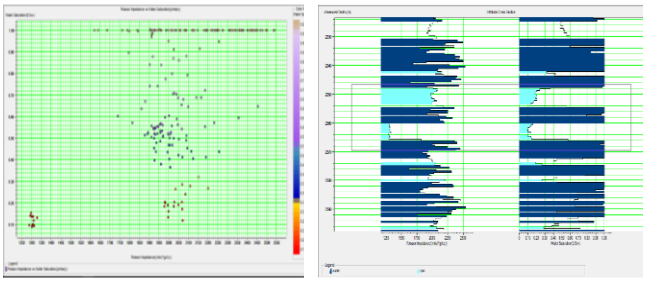


Fig. 7 Crossplot and cross section at well 81 of PI versus SW called as Fluid Impedance with *c* (1.376) can be seen by separating fluid content of the saturation value of water.

The separation of the fluid (seen at Fig. 8 and Fig. 9) became more evident by the parameter PI, Lambda-rho, and SW as the colors together in a crossplot. By correlating those results, there are similarities in zone 2360 to 2370 meter, where it shows a good match of low value SW that corresponds to low value of incompressibility, and the lithology has a low Gamma Ray reading. By combining the results from cross section and crossplot at well 81, the lithology impedance and fluid impedance in the depth 2360-2370 m is interpreted to be sandstone containing hydrocarbons. This is supported by LEMIGAS report stated that at depth of 2360-2370 m, well 81 contains hydrocarbon in thin reservoir.

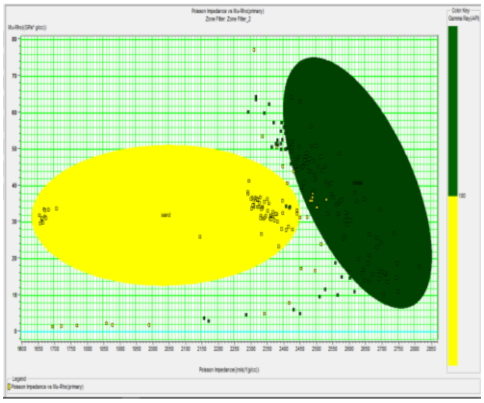


Fig. 8 Crossplot PI vs mu-rho at well 81, which can be seen that sand (yellow) and shale (green) are clearly separated.

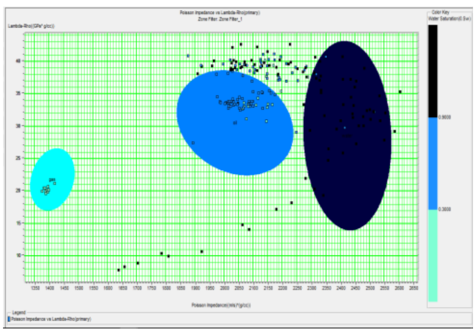


Fig. 9 Crossplot PI vs Lambda-rho at well 81 that the separation of HC (blue) and water (black) can be detected clearly and properly.

Lithology Impedance

The S-Impedance (*Zs*) from Simultaneous Inversion and mu-rho transformation can not clearly indicate where the sandstone zone is. Therefore, further analysis with Poisson impedance (PI) is needed to solve this issue. PI itself consists of two attributes, which are Lithology Impedance (LI) and Fluid Impedance (FI). Lithology impedance is the result of correlating PI with Gamma Ray which can give a better separation between the different lithologies, such as sandstone and shale. In Lithology impedance crossplot, low value of PI in the range of 1300-2500 (m/s)*(g/cc) is in the form of sandstone. The box area in Fig. 10 was sandstone with red color. From the Lithology impedance, volume slice can represent reservoir distribution. So, it can be presumed that the zone of red is a sandstone lithology interbedded with shale. The area between well 81 and 79 can be suspected to be a reservoir zone of hydrocarbon.

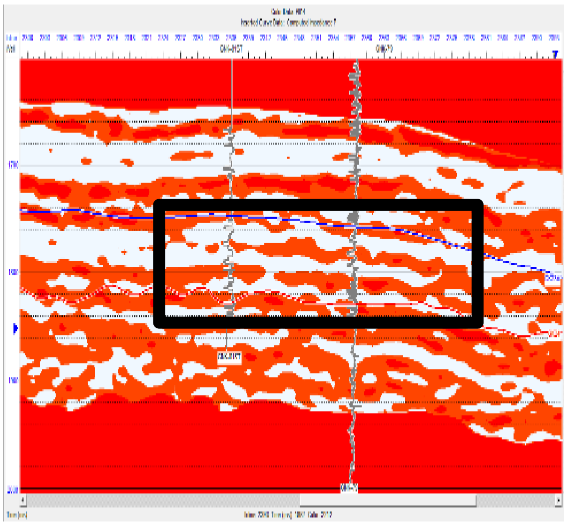


Figure 10. Lithology impedance analysis, it can be seen that the red color (in black rectangle) is a zone thought to be the reservoir where it has PI values that tend to be low to moderate.

Time slicing of Fig. 11 from top horizon GK23A until base horizon GK24 showed the hydrocarbon bearing reservoir at 1770-1820 ms (two-way-time). The low to moderate impedance (green yellow) within the black circle zone was indicated for sand reservoir. The reservoir is likely a thin reservoir layer, which appeared on the surface slicing of GK24-25 ms and GK24-20 ms. It tends to extend from Northeast to Southwest.

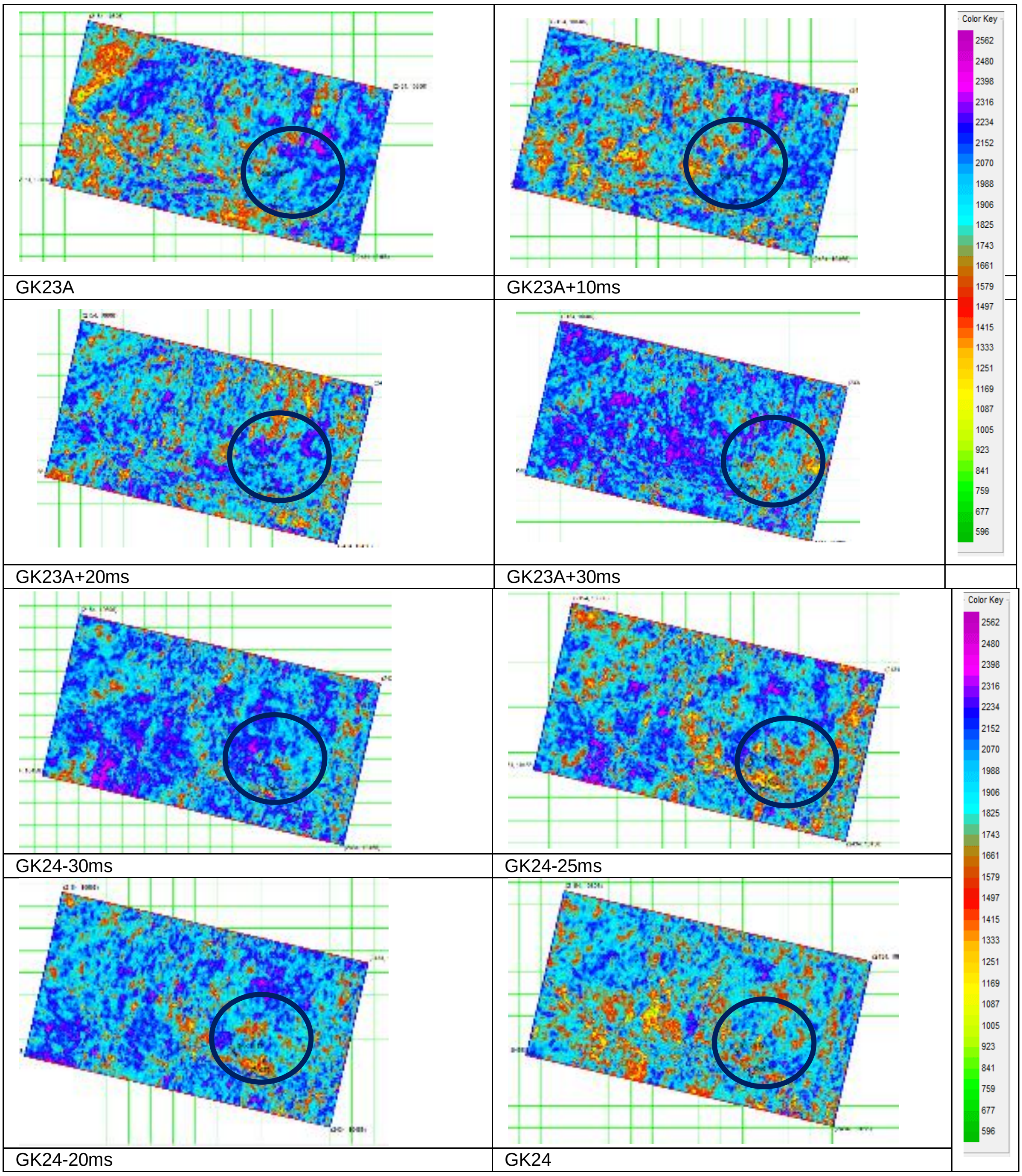


Figure 11. Surface/time slicing with Lithology Impedance scale. The low impedance (green yellow) shows the sand reservoir at interest zone of black circle.

Fluid impedance

Similarly, the seismic section was also performed in Fluid impedance volume to see the distribution of fluids in field "B" as seen in Fig. 12. The fluid of hydrocarbon may be indicated as red orange color within the interest zone. The horizon slicing on Fluid Impedance volume of Fig. 13, yellow green color was represented hydrocarbon, and it was more towards oil than gas. This analysis is also confirmed by the results of reservoir fluid analysis on well 79 and 81 that conducted by LEMIGAS. The thin oil reservoir is estimated to be at a depth of about 2360-2400 m below the surface.

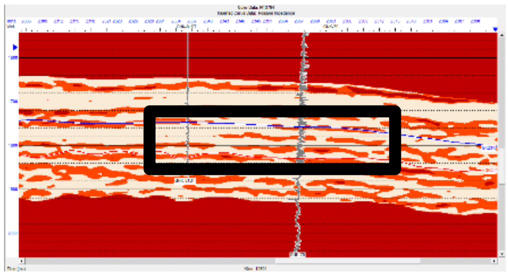


Fig. 12 Fluid Impedance analysis of field shows the low FI (red orange color) that interpreted as hydrocarbon layer.

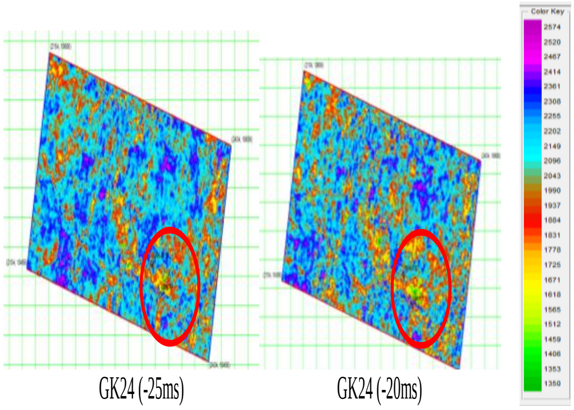


Fig. 13 Surface/time slicing with Fluid Impedance scale shows that the distribution of hydrocarbon is estimated at about 2360-2400 m below the surface.

CONCLUSION

Poisson impedance parameters are very sensitive to lithology and fluid content separation of reservoir. The method of TCCA (Target Correlation Coefficient Analysis) adds to the accuracy of calculation of *c* (optimization of the rotation) Poisson impedance to field "B". The separation between shale sandstone lithology in lithology impedance (PI-GR) obtained *c* at 1.3270. While the separation of hydrocarbon to water in fluid impedance (PI-SW) obtained *c* at 1.3764. Also by integrating geophysical and petrophysical data, it is known that the sandstone reservoir placed in Talang Akar Formation is thin layers with a thickness of about 40 m at a depth of about 2360 m. Its layer is identified as hydrocarbons which are dominated by oil rather than gas.

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