

---

## Simultaneous Seismic Inversion for Reservoir Characterization at Poseidon Field, Browse Basin, Australia

Suleman Mauritz Sihotang<sup>1†</sup>, Ida Herawati<sup>1</sup>

<sup>1</sup>Geophysical Engineering Study Program, Faculty of Exploration and Production Technology, Universitas Pertamina, Teuku Nyak Arief, RT.7 / RW.8, Simprug, Kebayoran Lama, South Jakarta, DKI Jakarta 12220, Indonesia

<sup>†</sup>[suleman.sihotang@gmail.com](mailto:suleman.sihotang@gmail.com)

---

Submitted: Februari 2021; Revised: March 2021; Approved: April 2021; Available Online: June 2021

---

**Abstrak.** Metode seismik inversi telah banyak digunakan untuk menghasilkan properti reservoir di lapangan minyak dan gas. Dalam penelitian ini, salah satu metode inversi yang dikenal sebagai inversi simultan digunakan untuk menganalisis karakterisasi reservoir di Lapangan Poseidon, Cekungan Browse. Inversi Simultan diterapkan pada data *partial angle stack* dan menghasilkan volume Impedansi Akustik (AI), Impedansi Geser (SI) dan parameter Lamé (LMR). Penelitian ini bertujuan untuk mengetahui sebaran litologi batupasir yang tersaturasi gas pada formasi reservoir Plover. Analisis sensitivitas dilakukan dengan *cross-plotting* antara parameter elastis dan parameter Lamé menggunakan lima data log sumur dan menganalisa jenis litologi dan fluida yang tersaturasi di dalamnya. Berdasarkan *cross-plot* tersebut, tipe litologi dapat diidentifikasi menggunakan parameter AI,  $\lambda\rho$ ,  $\mu\rho$ , dan  $\lambda/\mu$ . Sedangkan keberadaan gas dapat dibedakan dengan menggunakan parameter SI,  $\lambda\rho$ , dan  $\lambda/\mu$ . Keberadaan batupasir yang tersaturasi gas ditandai dengan nilai *Lambda-Rho* kurang dari 50 GPa g cc<sup>-1</sup> dan *Lambda over Mu* kurang dari 0,8 GPa g cc<sup>-1</sup>. Peta dari setiap parameter dihasilkan pada interval reservoir. Berdasarkan peta tersebut, dapat disimpulkan bahwa persebaran batupasir yang tersaturasi gas tersebar di wilayah timur dan barat daerah penelitian.

**Kata Kunci:** *Lambda Mu Rho, Inversi Simultan, Lapangan Poseidon*

**Abstract.** Seismic inversion method has been widely used to obtain reservoir property in an oil and gas field. In this research, one of inversion methods known as simultaneous inversion is used to analyze reservoir characterization at Poseidon Field, Browse Basin. Simultaneous inversion is applied to partial angle stack data and result in volume of Acoustic Impedance (AI), Shear Impedance (SI) and Lamé parameter (LMR). The objective of this study is to determine distribution of sandstone lithology with gas saturated in Plover reservoir formation. Sensitivity analysis is done by cross-plotting elastic and Lamé parameter from five well log data and analyzing lithology type and fluid saturation. Based on those cross-plots, lithological type can be identified from AI,  $\lambda\rho$ ,  $\mu\rho$  and  $\lambda/\mu$  parameters. Meanwhile, the presence of gas can be discriminated using SI,  $\lambda\rho$ , and  $\lambda/\mu$  parameters. Gas-saturated sandstone presence is characterized by Lambda-Rho value less than 50 GPa g cc<sup>-1</sup> and Lambda over Mu value less than 0.8 GPa g cc<sup>-1</sup>. Maps of each parameter are generated at reservoir interval. Based on those maps, it can be concluded that gas sand spread out in the eastern and western areas of research area.

**Keywords:** *Lambda Mu Rho, Simultaneous Inversion, Poseidon field*

**DOI :** 10.15408/fiziya.v4i1.19782

## INTRODUCTION

Poseidon field is a gas field located on the Australian North-West Shelf and discovered in 2009 with Poseidon-1 exploration well. Subsurface data is made available to public in 2017 by Geoscience Australia and ConocoPhillips as field operator. The open datasets consist of well data and seismic reflection data. Seismic reflection is geophysical method that primarily used in oil and gas exploration to obtain subsurface information in wide coverage.

In this study, Poseidon data will be interpreted quantitatively to provide us about layer property especially on property of reservoir interval. Reservoir properties such as lithology type and fluid saturation are very important to estimate hydrocarbon reserve and to define potential for field development. Lithology and fluid saturation information is obtained by analyzing log data from drilled well and need to be mapped through the area using seismic data. We will use seismic inversion method that integrate well log and seismic data to obtain property volume. Inversion method will result in acoustic/elastic parameter that can relate to reservoir property based on sensitivity analysis.

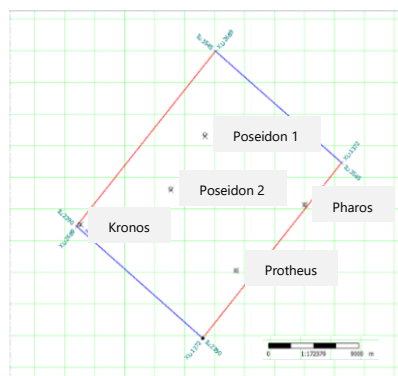
In this study, we use simultaneous inversion method that works on pre-stack gather or multi partial angle stack data. By using this inversion method, the volume of Acoustic Impedance (AI), Shear Impedance (SI) and density. From those volume, we can transform to other parameters such as Lamé parameters. By obtaining those parameters, the distribution of lithology and fluid will be mapped and analyzed at Poseidon Field.

## METHODS

### Data

The data used include:

- 1). Seismic data for partial angle stack in the form of near stack ( $6^{\circ}$ - $18^{\circ}$ ), mid stack ( $18^{\circ}$  -  $30^{\circ}$ ) and far stack ( $30^{\circ}$  -  $42^{\circ}$ ).
- 2). There are five well data (Kronos, Pharos, Poseidon 1, Poseidon 2 and Protheus) with log data consist of Gamma ray, Caliper, Resistivity, RHOB, NPHI, Vp, Vs, and Checkshot. The basemap of the research data is shown in Figure 1.



**Figure 1.** Basemap of the research area

### Methodology

Workflow of the entire process is shown in Figure 2. Data processing that will be carried out in this study consist of several main stages, such as:

### Sensitivity analysis

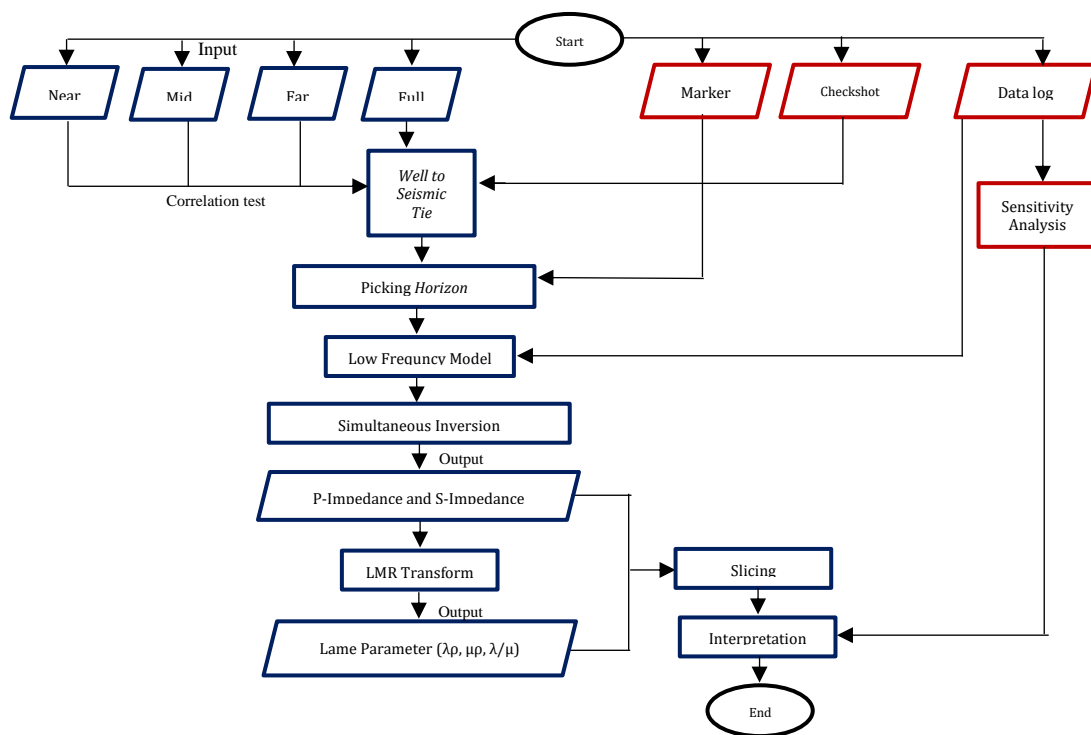
Sensitivity analysis is performed to determine the most sensitive parameters that can be used to analyze sandstone lithology zone and gas presence in the study area. This analysis is done by cross-plotting two parameters from log data and calculate shale Volumetric (Vshale) and water saturation (Sw) of each data point. The parameters tested are Acoustic Impedance (AI), Shear Impedance (SI), Lamda-rho, Mu-rho, and Lamda over Mu as well as Vshale and water saturation as the color key.

### Low frequency model

This process is used to add low frequency information to seismic data due to the limited frequency information on seismic. The model is built by interpolating impedance value from well log through study area guided by horizon interpretation.

### Inversion

This process is performed to extract impedance information from seismic data. The low frequency model and wavelet will be used as the input data along with the partial angle stack seismic data. By using the simultaneous inversion method, the volume of P-impedance, S-impedance, and density will be generated simultaneously.



**Figure 2.** Simultaneous Inversion Workflow

## FORMALISM

### Regional Geology

Poseidon field is located at Browse Basin, offshore of Western Australian. This basin lies from the northeast to the southwest of Australia. Reservoir interval is Plover formation which was formed in the Early to Middle Jurassic Extension phase [1]. During this phase, many small faults were generated which resulted in the collapse of anticline structure that had been formed in the previous phase. In this phase, fluvio-deltaic sandstones and shallow marine sandstones are deposited and accompanied by silt rock and a little carbonate rock deposition.

Plover formation is sandstone with gas accumulation. Its grain ranges from well to very good and is also mixed with other sandstones with medium to coarse grains. In this formation there are alternations with siltstone, claystone and also a little coal.

### Simultaneous Seismic Inversion

The seismic inversion used to obtain a model that describes physical properties of subsurface using information obtained from field data by utilizing information from impedance [2]. The earth's reflectivity model will be calculated from the input in the form of seismic response using an inversion algorithm. Based on input data, the inversion method is divided into two types: post-stack inversion and pre-stack inversion. Furthermore, the pre-stack inversion can also be divided into two methods based on the process, namely linear and non-linear methods. An example of a pre-stack seismic inversion method that uses a linear method is simultaneous seismic.

The process of simultaneous inversion is carried out using several inputs, namely seismic gather data or by combining partial angle stacks, low frequency models and wavelets. Mathematically, information on acoustic impedance (AI or  $Z_p$ ) and shear impedance (SI or  $Z_s$ ) is obtained from linear functions [3]:

$$\ln(Z_s) = k \ln(Z_p) + kc + \Delta L_d. \quad (1)$$

$$\ln(Z_d) = m \ln(Z_p) + mc + \Delta L_d. \quad (2)$$

A value of  $k$ ,  $kc$ ,  $m$ , and  $mc$  is obtained from relationship between  $\ln(Z_s)$  versus  $\ln(Z_p)$  and  $\ln(\rho)$  versus  $\ln(Z_p)$  as shown in Figure 3.

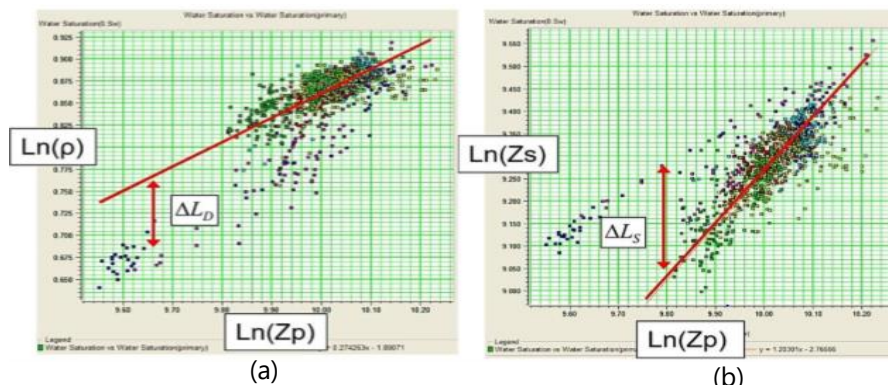


Figure 3. Cross-plots (a)  $\ln(Z_p)$  and  $\ln(\rho)$ , (b)  $\ln(Z_p)$  and  $\ln(Z_s)$  [2]

The deviations away from straight line,  $\Delta L_s$  and  $\Delta L_d$  are the desired fluid anomaly. By combining trace equation, Fatti's equation, and two equation above, angle trace equation is obtained as follow [3]:

$$T(\theta) = \acute{c}1W(\theta)DLp + \acute{c}2W(\theta)D\Delta L_s + W(\theta)c3D\Delta L_d, \quad (3)$$

where,

$$\acute{c}1 = \left(\frac{1}{2}c1\right) + \left(\frac{1}{2}\right)kc + mc3; \tag{4}$$

$$\acute{c}2 = \left(\frac{1}{2}\right)c2; \tag{5}$$

$$c1 = 1 + \tan^2\theta; c2 = -8\gamma^2\tan^2\theta; c3 = -0.5\tan^2\theta + 2\gamma^2\sin^2\theta; \gamma = \frac{Vs}{Vp}, \tag{6}$$

To solve equation (3), initial impedance model (low frequency model) is used and then iterate the equation using gradient conjugate method. The solution of acoustic Impedance ( $Zp$ ), Shear Impedance ( $Zs$ ), and density ( $\rho$ ) values is obtained as follows:

$$Zp = \exp(Lp). \tag{7}$$

$$Zs = \exp(kLp + kc + \Delta Ls). \tag{8}$$

$$\rho = \exp(mLp + mc + \Delta Ld). \tag{9}$$

### Lame Parameter

Lame parameter is a physical parameter derived from the equation for P-wave velocity ( $Vp$ ) and the S-wave velocity ( $Vs$ ). This parameter is used to determine physical properties of the rock, namely rigidity ( $\mu$ ) and incompressibility ( $\lambda$ ). Both of these physical properties can be used to identify reservoir rocks below the surface. The Lamé parameter [4] is derived as follows:

$$\mu\rho = Zs^2, \tag{10}$$

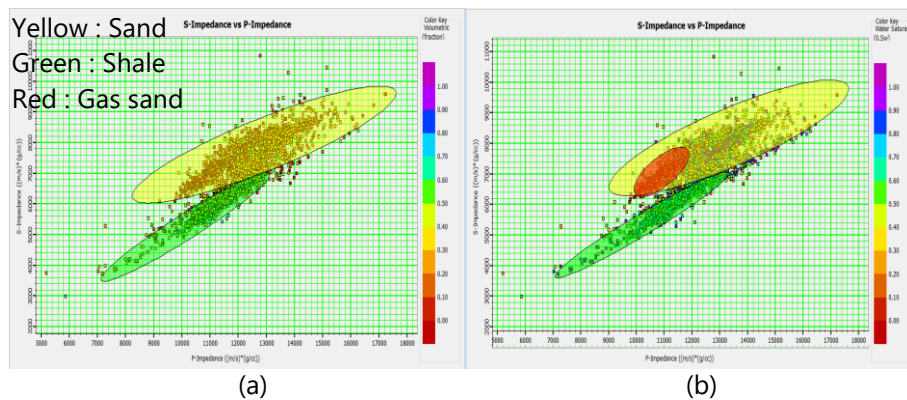
$$\lambda\rho = Zp^2 - 2Zs, \tag{11}$$

$$\lambda/\mu = \frac{\lambda\rho}{\mu\rho}. \tag{12}$$

## RESULT AND DISCUSSIONS

### Sensitivity Analysis

*AI vs SI*

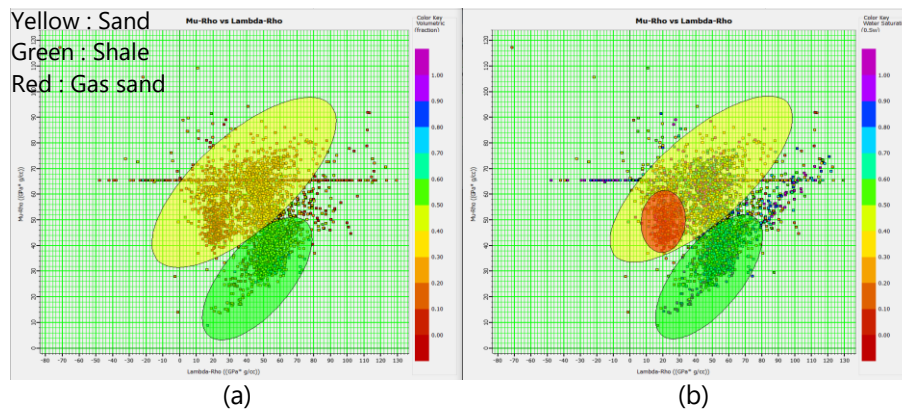


**Figure 4.** Cross-plot between log impedance P values and Neutron Porosity with information on the color key (a) Vshale and (b) water saturation

P-impedance log is cross-plotted with S-Impedance in color key Vshale (Figure 4a) and Water Saturation (Figure 4b). Figure 4a shows that in general, sandstone zone (yellow circle) has higher P-impedance and S-impedance value compared to shale zone (green circle). From the cross-plot, gas-saturated sandstone (red circle) has low P-impedance and low S-impedance compared to wet sand. However, gas sand is difficult to identified solely from two impedances since there is still overlap between those zones.

$\lambda\rho$  vs  $\mu\rho$

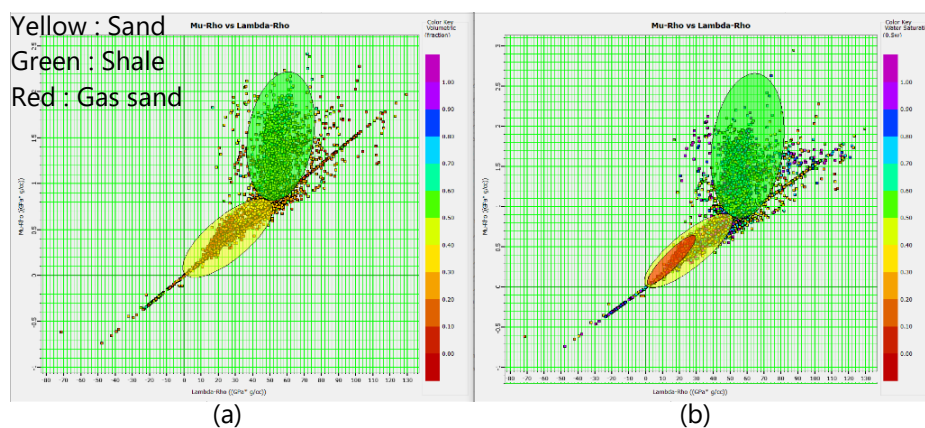
Figure 5 shows a cross-plot between  $\lambda\rho$  and  $\mu\rho$ . Sandstone zone has same range in  $\lambda\rho$  with shale zone and there is overlap between two zones for  $\mu\rho$  value (Figure 5a). Gas sand zone has low  $\lambda\rho$  value and low  $\mu\rho$  value compared to wet sand. However, there is still overlay between gas sand and shale (Figure 5b).



**Figure 5.** Cross-plot between log Lambda-Rho and Mu-Rho log values with information on the color key (a) Vshale and (b) water saturation

$\lambda\rho$  vs  $\lambda/\mu$

Cross-plot between  $\lambda\rho$  and  $\lambda/\mu$  shows good separation between sandstone and shale for  $\lambda/\mu$  value (Fig. 6a). From Fig. 6b, it can be seen that gas sand has low  $\lambda/\mu$  value and a low  $\lambda\rho$  value. In this cross-plot, there are no overlap zones between gas sand and shale.



**Figure 6.** Cross-plot between log Lambda-Rho and Lamda over Mu values with information on the color key (a) Vshale and (b) water saturation

From sensitivity analysis, it can be concluded that combination of Lamé parameter can differentiate gas sand presence. The value of elastic and Lamé parameter for each lithology are listed in Table 1 below.

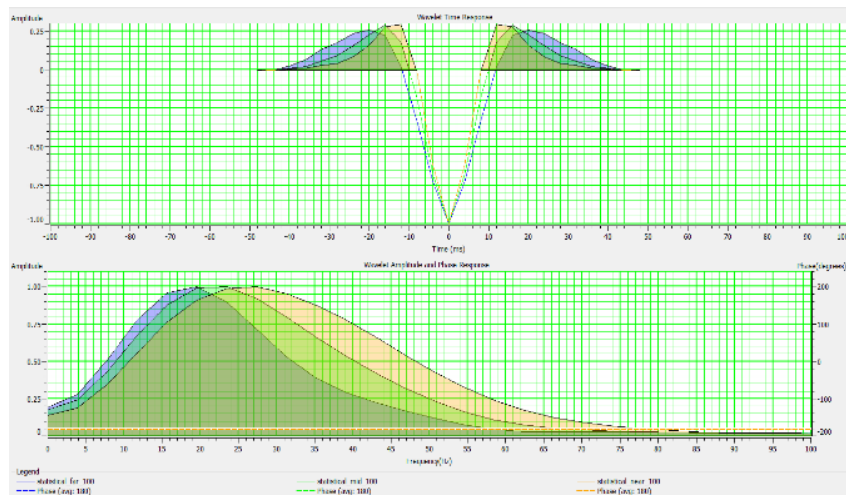
**Table 1.** Sensitivity analysis result

Lithology	AI ms <sup>-1</sup> gcc <sup>-1</sup>	SI ms <sup>-1</sup> gcc <sup>-1</sup>	λρ GPaGcc <sup>-1</sup>	μρ GPaGcc <sup>-1</sup>	λ/μ
Sand	9.000 – 17.000 (high)	6.500 – 10.000 (high)	0 – 50 (low)	35- 90 (high)	0 – 1 (low)
Shale	7.000 – 13.000 (low)	3.800 – 7.000 (low)	50 – 80 (high)	0 – 50 (low)	1 – 2.5 (high)
Gas Sand	10.000 – 12.000	6.500 – 8.000	0- 40	40 – 60	0 – 0,8

**Wavelet Estimation and Low Frequency Model**

Statistical wavelets are extracted from each partial angle stack with 100 msec length and time window around reservoir interval (Figure 7). The amplitude spectrum shows wavelet at near angle has higher frequency content compared to wavelet extracted from far angle. These wavelets will be used in the inversion process.

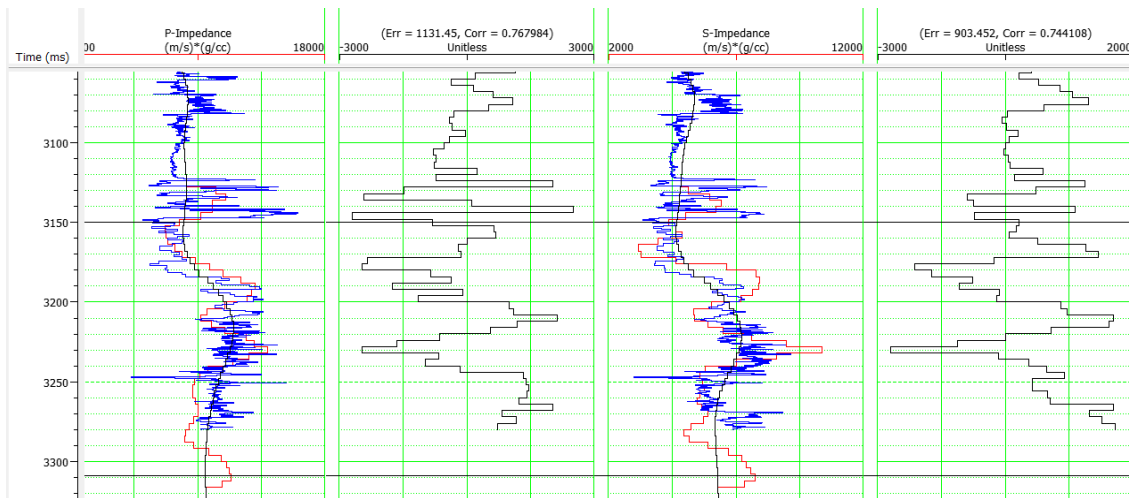
To build low frequency model, P-impedance and S-impedance data from five wells is interpolated through study area guided by top and base of Plover horizon.



**Figure 7.** Wavelet extracted at near (orange), mid (green), and far(blue) angle stack

**Inversion Result**

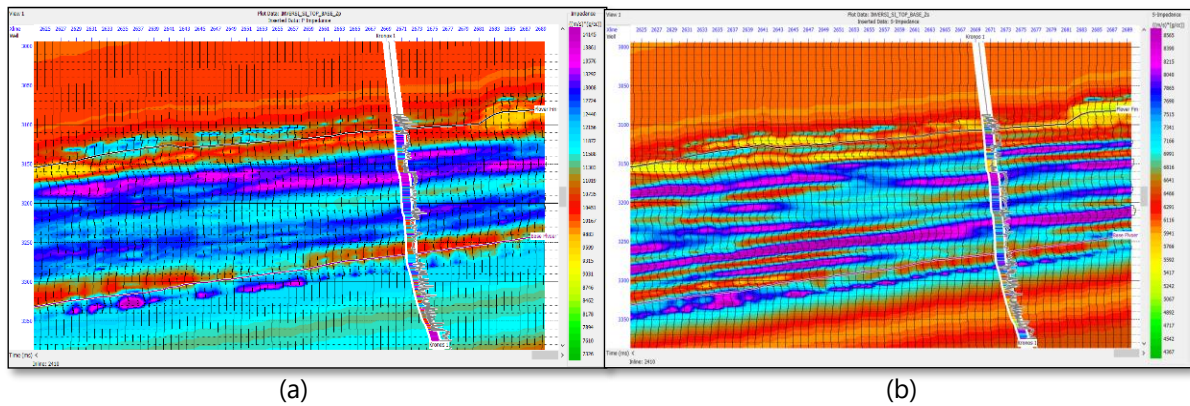
To check whether wavelets, low frequency model and inversion parameter is good enough, an inversion process is first applied at well location. Figure 8 shows an example of inversion analysis at Poseidon-1 with P-impedance and S-impedance inversion results (red curve), log data (blue curve) and low frequency model (black curve). P-Impedance inversion error for Poseidon-1 well is around 10% (compared to average P-impedance log) with correlation between log and inversion result is 0.77, and S-impedance error is around 14% with correlation 0.74. In average P-impedance error is around 10%, correlation 0.63 and for S-impedance is around 11% in error and its correlation is 0.61.



**Figure 8.** Inversion analysis at Poseidon-1 well

The inversion process is then applied to whole study area and will focus from the top to the base of Plover formation. Figure 9 shows inversion result of P-impedance and S-impedance at a line that passes Kronos well. From Figure 9a, there is low P-impedance value above base of Plover formation that might be related to gas presence.

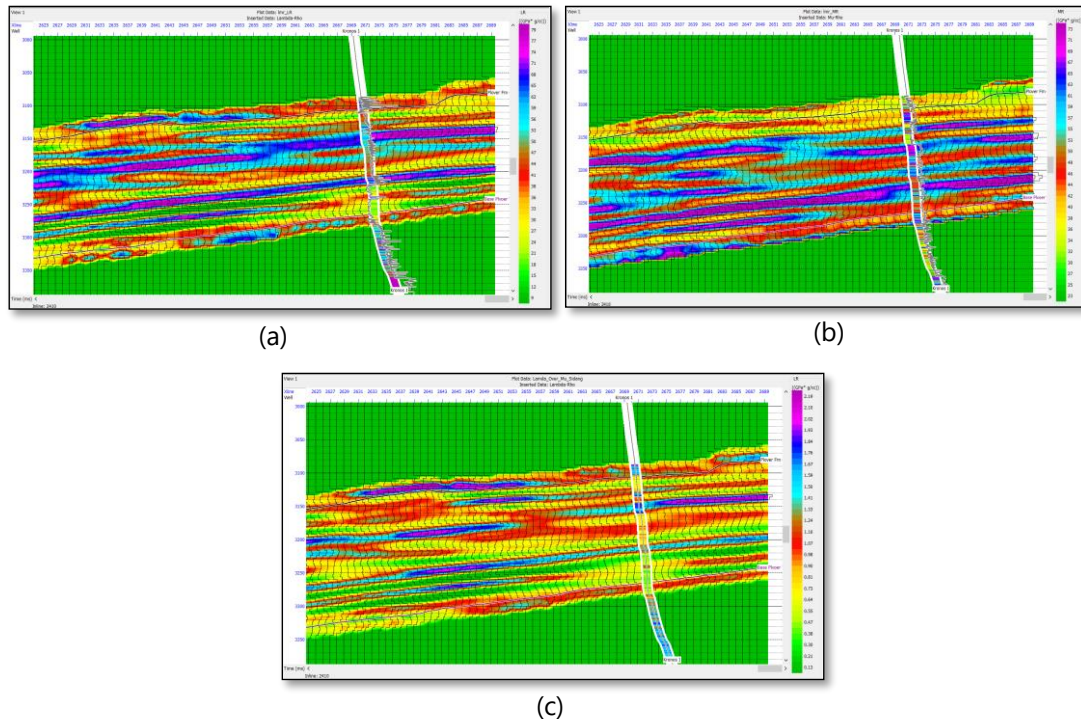
To obtained more information based on Table.1, volume of P-impedance and S-impedance resulted from simultaneous inversion will be transformed into combination of Lamé parameters ( $\lambda\rho$ ,  $\mu\rho$ , and  $\lambda / \mu$ ) volumes.



**Figure 9.** Inversion results around Kronos well (a) P-Impedance, (b) S-Impedance

Figure 10 shows combination of  $\lambda\rho$ ,  $\mu\rho$ , and  $\lambda / \mu$  parameter sections that passes Kronos well. Based on sensitivity analysis listed in Table 1, areas with low  $\lambda\rho$ , high  $\mu\rho$  and low  $\lambda / \mu$  values are estimated as gas sand interval in this study area.

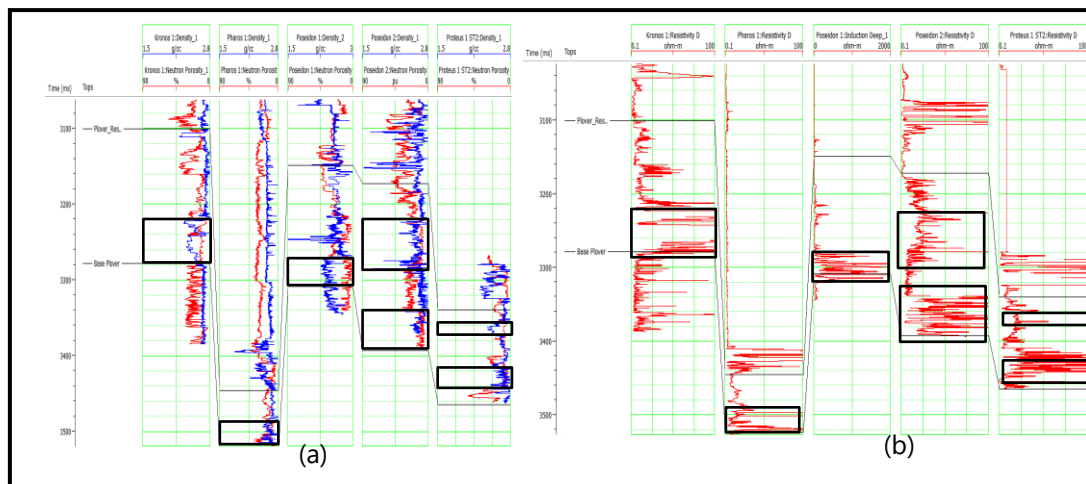




**Figure 10.** (a) Lambda rho, (b) Mu rho, (c) Lamda over Mu sections around Kronos well

**Identification of Gas Sand Distribution at Plover Formation**

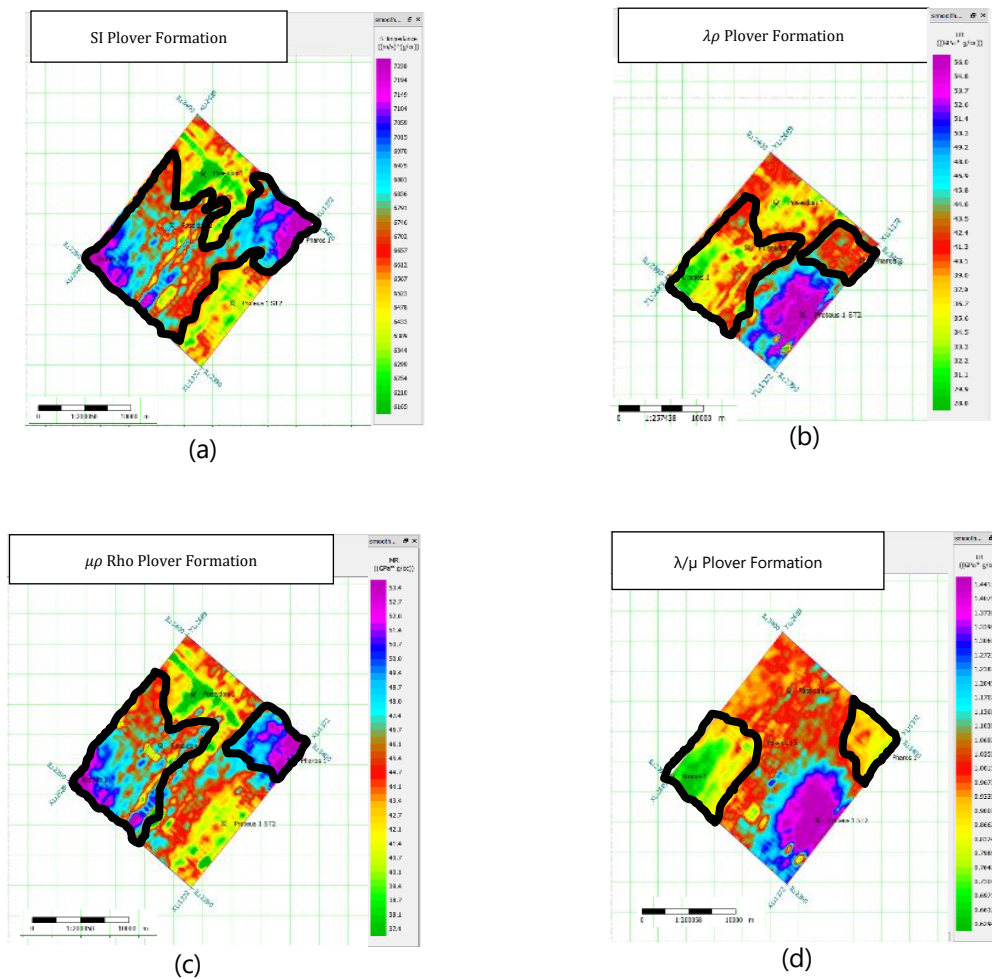
Based on the interpretation of the log data, it is known that the gas sand interval is around the base of Plover formation (Figure 11). Therefore, the map of elastic and combination of Lamé parameters will be extracted around base of Plover interval.



**Figure 11.** Interpretation of the gas sand zone at log (a) Neutron-Density and (b) Resistivity

Based on Table.1, S-Impedance (SI) value of gas sand is higher compared to surrounding. Figure 12(a) show SI map and zone with high SI value is inside the black polygon. Meanwhile, map of  $\lambda\rho$  around interval of interest is shown in Figure 12(b). The area with a low  $\lambda\rho$  value is also bounded by a black line. Based on those maps and combined with a  $\mu\rho$  map then we draw a polygon with high  $\mu\rho$  in Figure 12(c). The result of overlapping between three maps is considered so far as gas sand area.

To increase the accuracy of interpretation,  $\lambda / \mu$  is also mapped as shown in Figure 12(d). Area with low  $\lambda / \mu$  values is indicated by black polygon. Based on the overlay of all maps (AI, SI,  $\lambda\rho$ ,  $\mu\rho$ , and  $\lambda / \mu$ ), it can be concluded gas sand area spreads in the eastern and western areas of this research area. This zone is located near to Kronos well, Poseidon-2 and Pharos well. From quick look interpretation on the log data, those three wells contained thick gas sand near base of Plover formation. Further study on relationship between those parameters with gas thickness need to be carried out to have more understanding about reservoir characterization in this field.



**Figure 12.** (a)SI, (b)  $\lambda\rho$ , (c)  $\mu\rho$ , and (d)  $\lambda/\mu$  distribution map in plover formation

## CONCLUSIONS

From the results of this study, it can be concluded that:

- A. Parameters  $\lambda\rho$  and  $\lambda / \mu$  are the best parameters to identify the distribution of gas sand in this research area. The gas sand area will have a value of  $\lambda\rho$  less than 30 GPa g / cc while the value of  $\lambda / \mu$  will be less than 0.8 GPa g / cc.
- B. From inversion analysis, the average correlation between the inversion results and log data gives good correlation around 0.61 with 10% error both in P-impedance and S-impedance.

- C. Based on the results of the distribution of  $\text{AI}$ ,  $\text{SI}$ ,  $\lambda\rho$ ,  $\mu\rho$ , and  $\lambda / \mu$  values, it is known that the gas sand area is in the eastern and western areas of this research area.

## REFERENCES

- [1] Struckmeyer, H.I.M., J.E. Blevin, J. Sayers, J.M. Totterell, K. Baxter and D. Cathro. 1998. "Structural Evolution of The Browse Basin, North West Shelf: New Concepts From Deep Seismic Data". In *The Sedimentary Basin of Western Australia 2*, edited by P. G. Purcell and R.R. Purcell. 345 -367. Exploration Society of Australia.
- [2] Sheriff, Robert.2002. "Encyclopedic Dictionary of Applied Geophysics – Fourth Edition". Tulsa: Society of Exploration Geophysicists.
- [3] Hampson, Daniel P., and Brian H. Russell Brad Bankhead. 2005. "Simultaneous Inversion of Pre-Stack Seismic Data". *SEG Technical Program Expanded Abstract* 24(1):13-17.
- [4] Goodway, Bill, Taiwan Chen, and Jon Downton. 1997. "Improved AVO fluid detection and lithology discrimination using Lamé Petrophysical Parameters;  $\lambda\rho, \mu\rho$ , &  $\lambda/\mu$  Fluid Stack, From P and S Inversion". *SEG Technical Program Expanded Abstract* 1997 1: 183-186.