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# Evaluation of Post-stack Seismic Inversion Techniques for Detection of Sands in Gulf of Thailand

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**Abstract**

The majority of petroleum production in Thailand comes from the Pattani Basin of the Gulf of Thailand. The fluvial sands are the target reservoirs in this area. To predict these reservoirs is not always easy using conventional seismic amplitudes because of rapid lateral and vertical lithological variations due to the fluvial depositional environment. Rock physics analysis and different post-stack seismic inversion techniques were applied to detect sands within the study area. Moreover, the study also evaluates different post-stack seismic inversion techniques for accurate prediction of the sand reservoirs.

According to rock physics analysis, P-impedance can differentiate sands from shales in the shallow (from Middle Miocene Unconformity to Lower Middle Miocene) and deeper (below the Upper Lower Miocene) stratigraphic intervals, but not for the middle section in between that. Therefore, post-stack inversion solving for P-impedance is only suitable for shallow and deeper sections not for middle section. Model Based, Band limited and Spares-spike (Linear programming and Maximum likelihood) inversions show reasonable correlation at well locations whereas Colored inversion shows lowest correlation coefficient. Blind test results shows that Model Based inversion is more effective in area close to used wells for initial guess model, but Colored inversion performed better in the area away from the used wells for initial model. Model Based inversion scales P-impedance by using well data, whereas, Colored inversion is mostly seismic data driven. Therefore, in the case of good well control Model Based inversion works better, but in the case of poor well constraint, Colored inversion can provide reasonable prediction for P-impedance. The predicted P-impedances are low for sands in shallower and deeper sections. In the middle section, it is not easy to isolate sands from shales. In deeper section, sands with thickness less than 30 m cannot be detected on inverted volumes. This may be due to tuning phenomena. Sand bodies can be extracted along horizon slice by applying cutoff for P-impedance. Cutoff values for sand can be computed from cross-plots. The extracted sand bodies along horizon slices are promising targets for future exploration and development programs.

**Keywords**: Post-stack Seismic Inversion, Pattani Basin, Gulf of Thailand

## 1. Introduction

Since the 1970's, Acoustic Impedance (AI) has become a primary quantity used in seismic reflectivity inversion and interpretation (Lindseth, 1979) because of its direct correlation with rock properties. The impedance is extracted from seismic reflection data by a process usually called inversion.

The study area lies in Pladang2005 survey which is located in the Pattani Basin within the Gulf of Thailand. The basin contains Tertiary sediments and Tertiary fluvial and fluvio-lacustrine beds which are highly compartmentalized due to the rapid lateral stratigraphic changes. Due to complex stratigraphic geometries, it is not easy to predict reservoir sands in the area. This study aims to predict sand reservoirs in the area by applying post-stack seismic inversion techniques. Moreover, the study also evaluates different post-stack seismic inversion techniques for accurate prediction of the sand reservoirs.

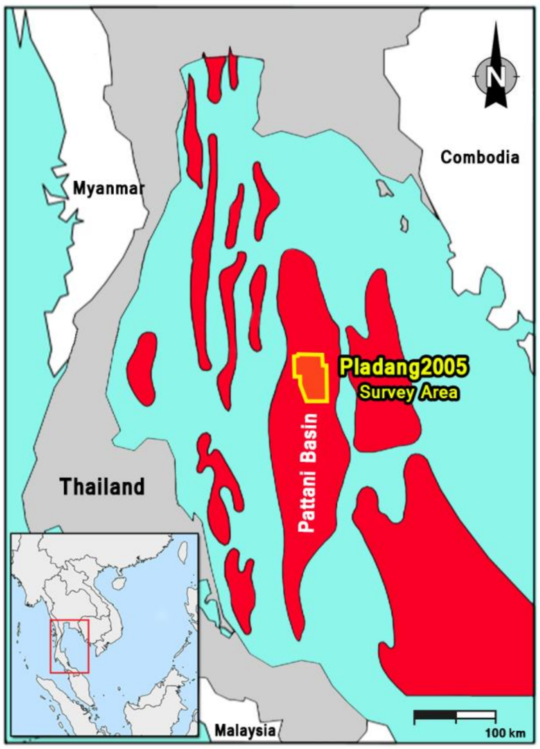


**Figure 1.** The study area lies in Pladang2005 Survey in the location of Pattani Basin, Gulf of Thailand

## 2. Methodology

### *Rock Physics Analysis*

Cross-plots of AI and density against shale volume color coded by water saturation were analyzed by using well data from eight wells. These cross-plots were prepared separately for different depth and stratigraphic zones to analyze the variation of different rock physics parameters in different depth and stratigraphic intervals. The cut-off for sand reservoirs is 30% shale volume.

### *Post-stack Seismic Inversion*

Two types of wavelet were extraction; statistical and extracted to perform the initial guess model, which provides low and high frequencies components missing from the seismic data, and helps in reducing the non-uniqueness of the solution. Then the initial guess model was generated by incorporating four interpreted horizons and well log data from eight exploration wells within the study area. Once the initial guess model is generated, five techniques of post-stack seismic inversion (Band Limited Inversion, Colored Inversion, Model Based Inversion, and two type of Sparse-spike Inversion which are Linear programming and Maximum likelyhood) can be performed.

### *Comparison for Different Post-stack Seismic Inversion Techniques*

Before generating each inversion model, checking the errors resulting from using each inversion method and parameters was done for minimizing these errors to make the inversion give more reliable results. Then, when all of the post-stack seismic inversion models were generated, the comparative analysis would be done to find the most reliable inversion model for the study area.

After the best model method was figured out, the model would be analyzed within depth function and also separately by stratigraphic sequence to verify the effect of depth and/or the change of the stratigraphic sequences to the rock physics parameters. Moreover, this best model would be compared to the result of amplitude extraction by using only the seismic data to predict the sand geometry with in the data slice.

## 3. Results and Discussion

### *Rock Physics Analysis*

In the vertical log section, sand shows the lower value of P-impedance and density compare to shale, regardless of water or hydrocarbon-saturated sand. The contrast of density value between sand and shale is significant at any depths while the contrast of P-impedance value can be divided into 3 main sections depending on stratigraphic sequence and depth change.

The shallow section (Figure 2a) starts from the shallow depths down to around 1850 m (MMU to Lower Middle Miocene). This section is easy to isolate sand from shale by using P-impedance. As depth increases, P-impedance trend is getting higher, especially in sand. This caused the less contrast of P-impedance between sand and shale in the middle section (Figure 2b) which is approximately in 1850 - 2550 m interval (Lower Middle Miocene to Upper Lower Miocene interval). For the deep section (Figure 2c) which is below 2550 m (below Upper Lower Miocene), the whole trend of P-impedance is also getting higher in response to depth increasing, but when compares to the middle section, P-impedance of sand trends to be lower again as in the shallow section. This made the contrast of P-impedance between sand and shale increases again. Anyway, the contrast of P-impedance in this section is not much significant difference as in the shallow section.

Cross-plots of P-impedance and shale volume in different sections indicate that P-impedance is dependent on depth and lithology. Clean sands have relatively low P-impedance than shales at the shallow section so they can be isolated from shales based on P-impedance contrast. However, hydrocarbon-saturated sands cannot be distinguished from water sands using this cross-plot (Figure 3a). For shaly sands (P-impedance > 7000 m/s*g/cc), their P-impedance values are same as of shales. The cross-plot of the middle section shows that sands and shales both have P-impedance in same range greater than 8000 m/s*g/cc (Figure 3b). Therefore, made these two lithologies cannot be separated by using P-impedance contrast in the middle section. However, in the deep

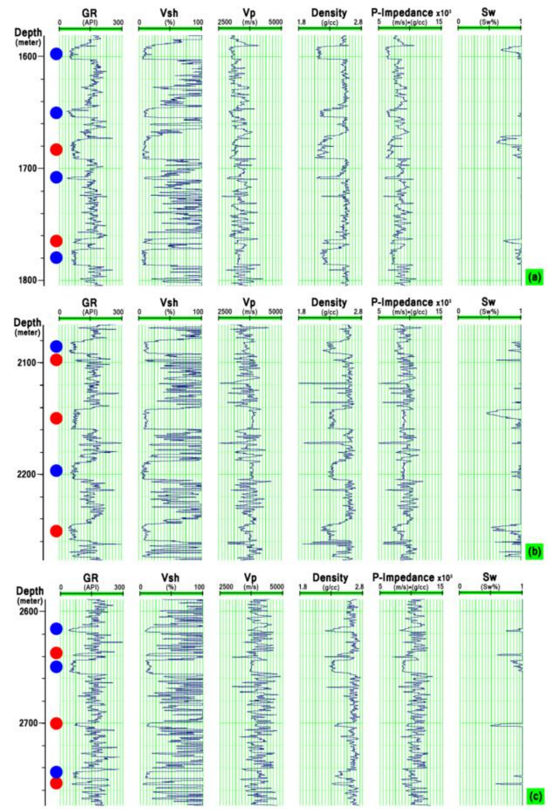

**Figure 2.** Gamma-ray, shale volume, sonic, density and water saturation logs with computed P-impedance log in (a) Shallow section, (b) Middle section, and (c) Deep section below M marker. Red and blue circles indicate hydrocarbon sands water-wet sands.

section, clean sands (P-impedance < 9500 m/s*g/cc) and shales can be partially isolated as in the shallow part. The hydrocarbon-saturated sands are also not outstanding from water sands as in the cross-plot (Figure 3c). Consequently, post-stack seismic inversion technique, will only be suitable to detect clean sands from shale within the shallow section and up to some extend in the deep sections. But in the middle section, the P-impedance inversion will not be suitable to discriminate the lithology in the study area.

### *Post-stack Seismic Inversion*

Correlation coefficients of match between synthetic and real seismic were observed for statistical and extracted wavelets. The results

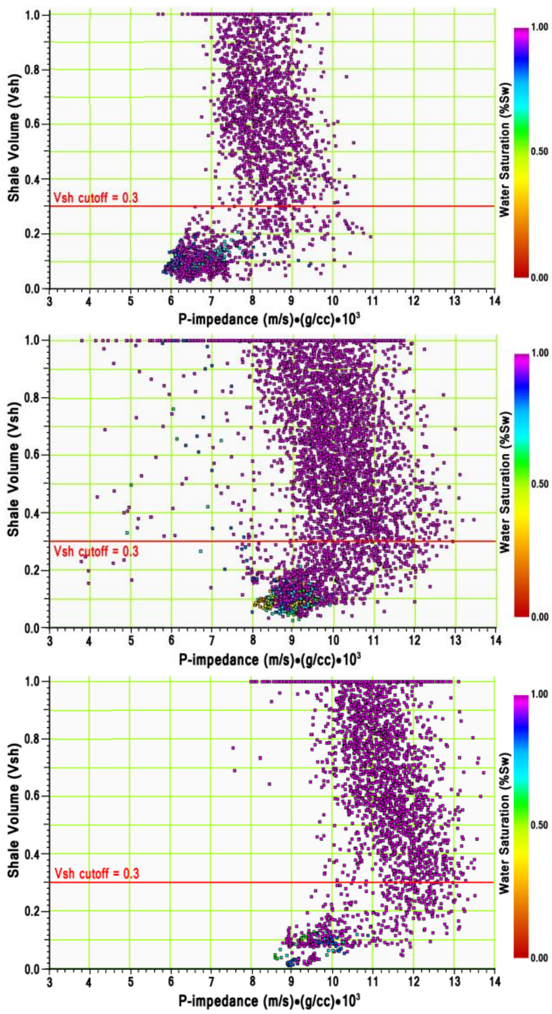


**Figure 3.** Cross-plot of P-impedance and shale volume for (a) shallow section, (b) middle section, and (c) deep section below

show that extracted wavelet is more suitable for well to seismic tie and inversion process.

The initial guess model is the next step of inversion process. It was generated within time window from 1000 to 2500 ms which covers the available well log data of eight wells used in inversion process (1300 – 2300 ms). As generally very low frequencies are missing from seismic data, therefore we need to add these low frequencies by using log data. Amplitude spectrum analysis shows that frequencies below 5 Hz are not present in the seismic data so high-cut filter of 5 Hz was applied for generating the initial guess model. Figure 4 shows the cross-sections along the in-line which cut into #P-05 well of high-cut 5 Hz filtered P-impedance model. These figures reveal that in general the P-impedance values increase from top to bottom which are ranging about from 6000 to 12000 m/s*g/cc for this model.

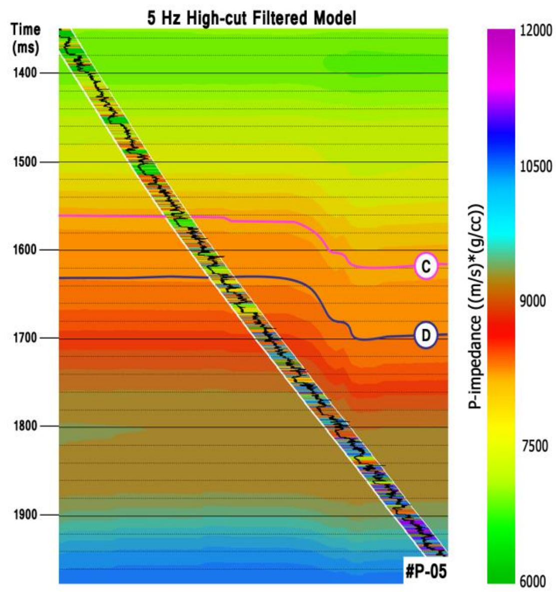


**Figure 4.** Cross-section of 5 Hz high-cut filtered models along inline across #P-05 well. Gamma-ray curve log is displayed with variable color log of P-impedance value.

In order to use optimum parameters for different inversion process, different values of parameters were applied and best one was selected based on QC analysis.

***Comparative analysis***

*Comparison of inverted P-impedance to original logs had been done by* cross-plot between the original and inverted P-impedance logs color coded by well name analyzing. Colored inversion shows the worst value of correlation at 0.70 with scattered data points (Figure 5). Other four types of inversion show the same range correlation number at around 0.80 with good trend of the data points. Moreover, Colored inversion shows the highest RMS error number ranges of correlation for 8 well data used because this technique is mostly seismic driven.

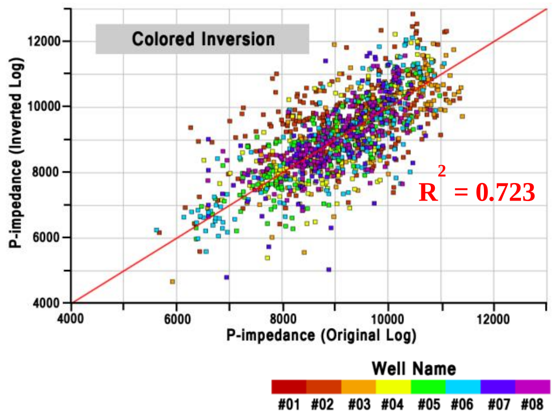


**Figure 5.** Cross-plots between original and inverted P-impedance log for Colored inversion

*Comparison of P-impedance log and inverted volume* is observed a good match result for low P-impedance inversion and well data within the shallow section except for both types of Spares-spike inversion (Linear programming and Maximum likelihood). Other three inversion techniques (Band Limited, Colored, and Model Based inversions) yield reasonable results matching with well data (Figure 6). In the middle section, the predicted inverted volume do not show good match. Sands do not always correspond to low P-impedance. The same results were indicated by rock physics analysis as sands and shales have similar P-impedance for this interval. For deep section, only sands with thickness more than 30 m can be detected on inverted sections. This also corresponds to rock physics analysis, which indicated that in deeper section, sands and shales could be partially differentiated by using P-impedance.

*Blind test analysis* was performed for the wells, which were not used in initial model. The following section shows the comparison of two different wells, which are located in different locations and structural types. The first well#T-01 was drilled in simple structure downthrown side of faulted block. Moreover, its location is only 1.5 km apart from Well #P-06, that was used in the initial guess model. The second well was drilled in complex structure due to faulting and it was

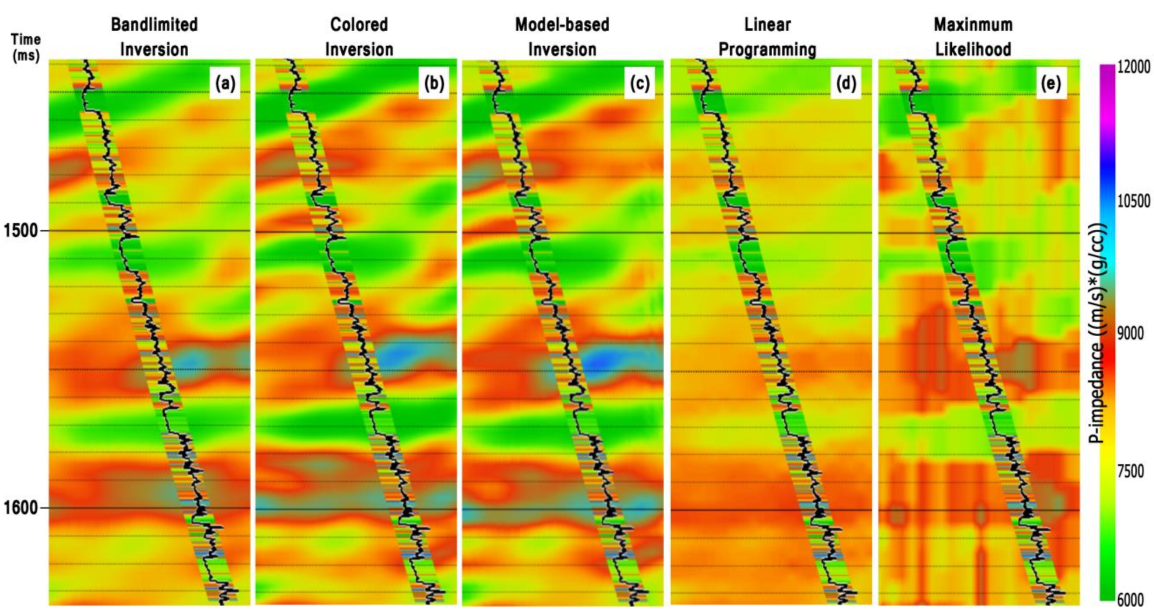


**Figure 6.** Cross-section of all inversion models along inline across #P-05 well in the shallow section with gamma-ray log (black) and color filled by P-impedance log value displayed.

drilled in footwall side. Well #T-02 is far away from wells used in the initial guess model. The closest well data used for initial model is more than 5 km away from Well#T-02. This well is located within closely spaced faults.

Well #T-01 shows good match with inverted volumes of all inversion techniques, except two Sparse-spike inversion techniques (Linear programming and Maximum likelyhood). Other three techniques (Band Limited, Colored, and Model Based inversions) show closely related results with good matching of low P-impedance inverted volume and well log data but the best result is observed from Model Based inversion (Figure 7a). Blind test for well #T-02 show poor match in the case of all inversion techniques except Colored inversion (Figure 7b). This may be due to two reasons; 1) well #T-02 is far away from the wells used in the initial guess model, 2) well #T-02 is located in complex structure. Colored inversion gives comparatively better result as this technique is not based on the initial guess model.

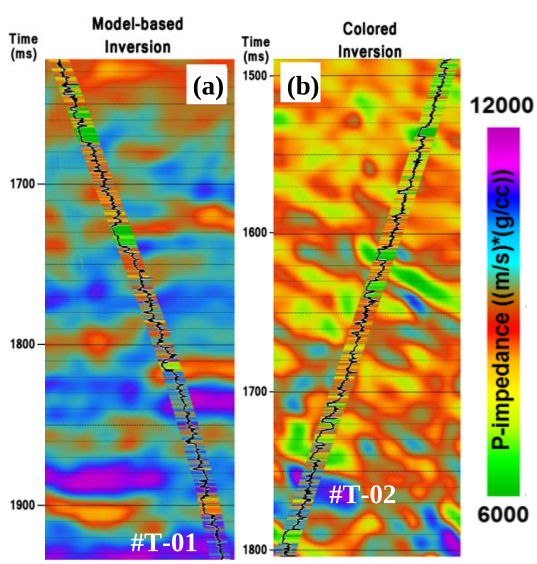


**Figure 7.** Cross-section of Model Based and Colored inversion models along inline across #T-01 and #T-02 well at the shallow section with gamma-ray log (black) and color filled by P-impedance log value displayed.

*Interpretation of sand distribution*

Model Based inverted P-impedance volumes were extracted along horizon slices image to detect lateral distribution of sands (Figure 8). The figures reveal that sands are mostly located in the central and northern part of the area. In the northeastern side of the area, sinuous feature like channel belt is observed. Moreover, RMS amplitude map shows high amplitudes at the location of sand bodies. This supports that P-impedance inversion is reliable.

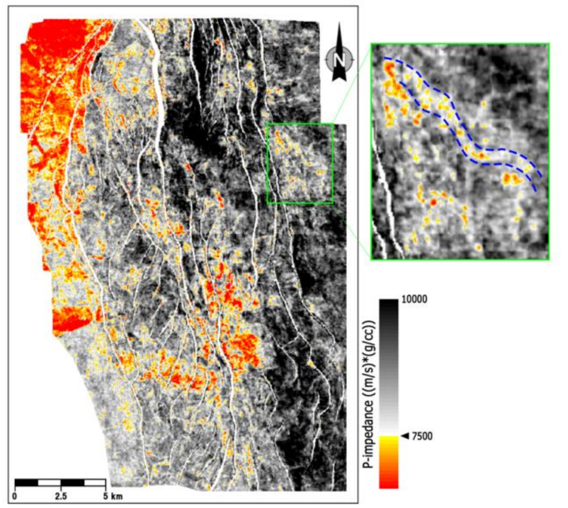


**Figure 8.** Model-based inverted P-impedance data slice extracted with close-up map of sand distribution relatives to channel.

## 4. Conclusions

Key findings and conclusions are summarized below.

• P-impedance can differentiate sands from shales in the shallow and deep sections but not for the middle section in between that. Therefore, post-stack inversion solving for P-impedance is only suitable for shallow and deeper sections not for middle section.

• Density can discriminate sands from shales for all depths. Sands always show lower density than shales. This may useful for identification of the sands within the middle section, which is impossible to do by using only P-impedance. Pre-stack inversion for density maybe the best for lithology predict-tion in the study area.

• Model Based inversion show best corre-lation when compared at well locations. The other inversion techniques such as Spares-spike (Linear programming and Maximum likelihood) and Band Limited inversions also show reasonable match at well locations. The worst correlation coefficient is obtained for Colored inversion. Colored inversion is most-ly seismic data driven, while other techniques are depending upon initial guess model. Therefore, at used wells for model, other techniques are showing better correlation co-efficient than Colored inversion.

• Blind test was performed for two wells. Well #T-01 is 1.5 km apart from nearest used well and Well #T-02 is more than 5 km apart from the nearest used well in the initial guess model. Well #T-01 shows very good match of actual and predicted P-impedance for Model Based inversion. However, Well#T-02 shows best match for Colored inversion. This may be because Model Based inversion is more effective in the case of good well control and not suitable for the area with less well control. Whereas, Colored inversion, which is seismic data driven can works comparatively better in the case of sparse well control.

• The predicted P-impedances are low for sands in shallower and deeper sections. In the middle section, it is not easy to isolate sands from shales. In deeper section, sands with the thickness less than 30 m cannot be detected in the inversion. This may be because of tuning effect.

• Sand bodies can be extracted along hori-zon slice by applying cutoff for P-impedance. Cutoff values for sand which were computed from cross-plots analysis. The extracted sand bodies along horizon slices are promising targets for future exploration and develop-ment programs.

## 5. Acknowledgements

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