Integration of fluid replacement modeling and seismic AVO analysis towards simultaneous seismic inversion to delineate the distribution of Globigerina limestone gas reservoir

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Abstract. Integration of fluid replacement modelling and seismic AVO analysis towards simultaneous seismic inversion had been done to delineate the distribution of Globigerina limestone gas reservoir in Madura Strait, East Java Basin. This study was using backward modelling or well known as inversion modelling to finish the quantitative analysis. The purpose of the study is to map the distribution of Globigerina limestone gas reservoir so that in the end the final result will be used as a guidance to drill the next exploration well. It started with an optimized low frequency model building by integrating fluid substitution modelling and seismic AVO analysis. By integrating these two methods, the distorted top and bottom reservoir can be compensated, and the low frequency model will be optimized. The availability of the data includes 3D seismic data with acquisition bin size 18.75 m x 12.5 m, with two well logs. The cross plot result showed that the reservoir and non-reservoir lithology can be distinguished by Vp and Vs log. By analysing the acoustic impedance together with Vp/Vs ratio, the character of gas reservoir at surrounding F and H structures can also be delineated. The main cut off for acoustic impedance and Vp/Vs ratio were 5,500 gr/cm 3*m/s and 2.0. The final optimizing result of low frequency model showed that the target G structure, which will be the next exploration target, showed an analogue response with its neighbour F and H structures. It is concluded that by integrating both two methods, fluid replacement modelling and AVO seismic analysis, the optimizing of low frequency model can be achieved and the simultaneous seismic inversion can successfully map other gas reservoir.

Keywords: Fluid replacement modelling, AVO seismic analysis, simultaneous seismic inversion, globigerina limestone, East Java Basin

1. Introduction

Madura Strait is part of the East Java Basin that for almost 30 years had been one of successful petroleum system, both for thermogenic and biogenic system. For biogenic classes, a bio-elastic reservoir known as Globigerina limestone has been discovered and developed along this area. The key feature that influenced the seismic clarity for this area is the abundance of shallow gas masking. It may
affect the way interpreter to pick the seismic horizon. Seismic data is a product of forward modelling utilizing earth reflectivity series, convolved with source signal or wavelet to create seismic trace. Seismic inversion is a backward process to gain earth layer model that represents subsurface geological information. One of the problems that seismic inversion faced is the non-uniqueness. Hampson et al. stated that the invers matrix algorithm could not recover the low frequency content of seismic data [1]. In this case, it is not recommended to directly inverse seismic data because the result will only be based on seismic frequency bandwidth. To make it more geologically make sense, it is needed to introduce the low frequency model from the beginning. Simultaneous seismic inversion is one of the methods that based on low frequency model building. By using the log information, Zp, Zs, and density, the low frequency model can be build and iteratively updated so that the smallest error to the real seismic gathers can be achieved and narrowing the non-uniqueness into optimum subsurface geological model [1].

In this research, we have integrated the using of fluid replacement model and seismic AVO analysis to optimize the low frequency model building. The result shows that by firm and valid low frequency model, the simultaneous inversion result is more geologically make sense, the impedance model is more reliable, and it can be used to help delineating gas reservoir at other prospect area.

2. Method
In this study, several data have been utilized including 3D post stack data, 3D pre stack data, 2 discovery wells, and check shot. CGG Hampson-Russell is the main core to do the simultaneous seismic inversion. The process includes well to seismic tie, cross plot analysis, and inversion itself. Meanwhile, for the fluid substitution modelling and sensitivity analysis are using Rokdoc. After top and bottom reservoir validation, the seismic interpretation is based on Petrel software and there are several output surfaces that will be the input for low frequency modelling, to achieve an optimized simultaneous seismic inversion [1].

Main focus of this method is about optimizing the low frequency model as the geological trend of this field. By doing the fluid replacement modelling and seismic AVO analysis, the container of gas reservoir is well defined. From these two known wells, the top and bottom of reservoir is trough at top and peak at bottom in Well H. Peak for both top and bottom in Well F. G Structure with no exploration well, utilized seismic AVO analysis and found that the top reservoir as trough and bottom reservoir as peak.

Pre stack seismic inversion not only generated P-impedance volume, but also S-impedance and density. These combinations gave more sensitivity analysis to the fluid content inside the reservoir. The non-uniqueness problem had been decreased by introducing another horizon at the top and base of the reservoir target. The wavelet also had been analysed and concluded of which wavelet is the most applicable for every structure. Based on Fatti et al. (1994), formulation and further simplification, there is a linear connection between Lp to Ls and between Lp to density [2]. This is the key of how good the simultaneous inversion analysis later, and the key of how match impedance model to the real log data.

3. Results and discussion
Based on sensitivity analysis, cross plot between P-impedance and Vp/Vs ratio helped in differentiating between the reservoir and non-reservoir zone. This also became the basis of choosing which quantitative seismic analysis that is effective to delineate other gas reservoir at other structure. P-impedance cutoff for gas reservoir is 5,500 gr/cm³*m/s with Vp/Vs ratio less than 2.0. It is shown by the red dot accumulation at bottom left corner. The overlain shale has low P-impedance value less than 4,000 gr/cm³*m/s with Vp/Vs ratio above 2.5 (figure 1).

To determine the top and bottom reservoir in H structure and F structure, fluid replacement modelling had been done in Well F and Well H. Based on the in-situ log, the top reservoir responded
as trough in Well H and responded as peak in Well F. Based on this, the AVO modelling will then clarify which AVO class they are in (figure 2). Several seismic horizons then be picked to build the gas reservoir container including T63 horizon as top of seal, T60 as top of gas reservoir, DHI as the bottom gas reservoir, and T40A as the base for seismic inversion window. T63 and T40A will be the top and base during the simultaneous seismic inversion process.

The limitation of seismic bandwidth, especially at the low frequency content, made the impedance model contained the relative value of AI. To introduce the geological trend into the final model, it is needed to introduce the low frequency modelling as the background trend where the high frequency will suit themselves toward this trend [3]. There are several data that can be used as low frequency model guide, such as seismic velocity data, filtered well log data, or even a compaction data. Each data will fill the low frequency spectrum into the model, for example 0–3 Hz from seismic velocity data and compaction data, 3–10 Hz from filtered well log data, and 10–60 Hz from the seismic frequency bandwidth. The low frequency model used as the source of low frequency content in this research came from filtered well logs of Well H and Well F, and then extrapolated into 3D area. Those 4 surfaces, T63, T60, DHI and T40A, are used as the lateral guidance of the initial model (figure 3).
Before executing the simultaneous inversion algorithm, inversion analysis is needed to justify how good the correlation of the final model will be when put it side by side with original well logs. Refer to Well F and Well H, there is a good match in term of P-impedance model, S-impedance model, Density Model, even for Vp/Vs ratio model. By utilizing angle dependent wavelet (figure 4), the correlation between synthetic and real gather are 0.94 and 0.92 (figure 5). This means that the inversion parameter is good enough and allowed to proceed to the inversion process. Best straight line that fit in in (Zp) cross plot is the key to have a reliable final simultaneous seismic inversion result (figure 6).

![Figure 3](image)

(a) F Structure, (b) H Structure and (c) G Structure.

**Figure 3.** Initial low frequency model at each reservoir’s target, (a) F structure, (b) H structure and (c) G structure.

![Figure 4](image)

**Figure 4.** Angle dependent wavelet extracted statistically from the angle gathers.
Optimization of low frequency model is one of the tools to minimize the non-uniqueness result of seismic inversion algorithm. Using several horizons as lateral guidance allowed the impedance model to be more geologically make sense. The variation of shale thickness that overlain the top gas reservoir, gave a more appropriate value of final impedance model for all of the structure.

This impedance result can be used to characterize the next prospect, the G structure, at southern part of two successful gas discovery, F and H structures. In term of characterizing the reservoir’s property, the simultaneous seismic inversion has several output models such as P-Impedance, S-Impedance, and density. Based on P-Impedance vs Vp/Vs crossplot, we know for sure what is the gas reservoir cut-off. To characterize the reservoir’s lithology point of view, the final P-impedance model will delineate the distribution of gas reservoir [4-6]. The low P-Impedance anomaly will guide us to find where to look. Meanwhile, to characterize the reservoir’s fluid property, the Vp/Vs model will also culminate the gas bearing area at each structure. All of these features are summarized in the below section (figure 7). G structure as the next prospecting area is needed to be evaluated as the next exploration target. In this study, the G structure has the same low impedance anomaly as in proven gas
Figure 7. Reservoir characterization based on simultaneous seismic inversion, (a) F structure, (b) H structure and (c) G structure.
reservoir at H structure. Moreover, the fluid characterization below this field, also shows a good gas anomaly response as in both H and F structure.

4. Conclusion
The result of this research shows that the integration of fluid replacement modelling and seismic AVO analysis will help in optimizing the low frequency model and delineating the distribution of Globigerina limestone reservoir. This approach is needed due to the loss of low frequency content in the seismic data. The non-uniqueness problem was also reduced by applying several surfaces as the lateral control of the initial model. It will make the final impedance model to be more geologically accepted and reliable to reflect the geological condition under the surface. The lack of top and bottom determination will affect to failure in gas reservoir modelling validity, since this top and bottom is the key to distribute the lithology parameter from the known wells.

Based on this simultaneous seismic inversion methodology with a more valid initial model at the beginning, the output reservoir property model for the G structure is satisfactory. The gas anomaly is shown by the low Vp/Vs value, with a good reservoir property that may be indicated from the low P-Impedance value at this structure. It means that the structure has a good chance in containing hydrocarbon.

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