Application of Seismic Inversion to the Gas Field Development

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Abstract: Proper reservoir characterization is an integral part of formation evaluation, reserve estimation and planning of field development. Seismic inversion is a widely employed reservoir characterization tool that provides various rock properties of reservoir intervals. This study presents results of the inversion studies including Geostatistical Inversion carried out on the gas fields, offshore Myanmar. Higher resolution and multiple models can be produced by Geostatistical Inversion using input data such as pre-stack seismic data, well logs, petrophysical relationships and geological inferences for example reservoir shape and lateral extent. Detailed reservoir characterization was required for the development plan of gas fields, and the Geostatistical Inversion studies served as a basis for integrated geological modeling and development well planning.

Keywords: reservoir characterization, inversion, Geostatistical Inversion, gas field

1. INTRODUCTION

Since the first gas discovery at the Shwe-1/1A exploratory well in 2004 by Daewoo consortium, extensive exploration and appraisal works had been performed in the northeastern offshore Myanmar (Fig. 1). Three gas fields named Shwe, Shwe Phyu and Mya, have been discovered. The gas reservoirs are late Pliocene deep-marine turbidite sandstones ranging about 2,900– 3,200 m, TVDSS. The final development plan for the gas fields in under way, and the entry into the development period will be made in the near future.

It is difficult to characterize reservoir properties just using seismic amplitude because seismic amplitude is not a rock property but an interface property. In order to obtain a rock property from the seismic data, inversion process is used widely for reservoir characterization. Inversion is the transformation of seismic data into pseudo P-impedance logs at every trace and all information in the seismic data is retained (Latimer, 2000). P-impedance which is a result of the inversion process is the product of P-wave velocity and density.

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A series of inversion processing has been attempted in the Shwe, Shwe Phyu and Mya fields during exploration and appraisal stages from 2004 to 2007. The main objectives were to define prospects and determine the exploration and appraisal well locations. The high resolution 3D Geostatistical Inversion study has been performed over the gas fields from 2008 to 2009 as well. This study focuses on the use of lithology, fluid and petrophysical properties inverted directly for reservoir characterization. The present study describes inversion works carried out for the three gas fields with emphasis on Geostatistical Inversion used for geological modeling and field development planning.

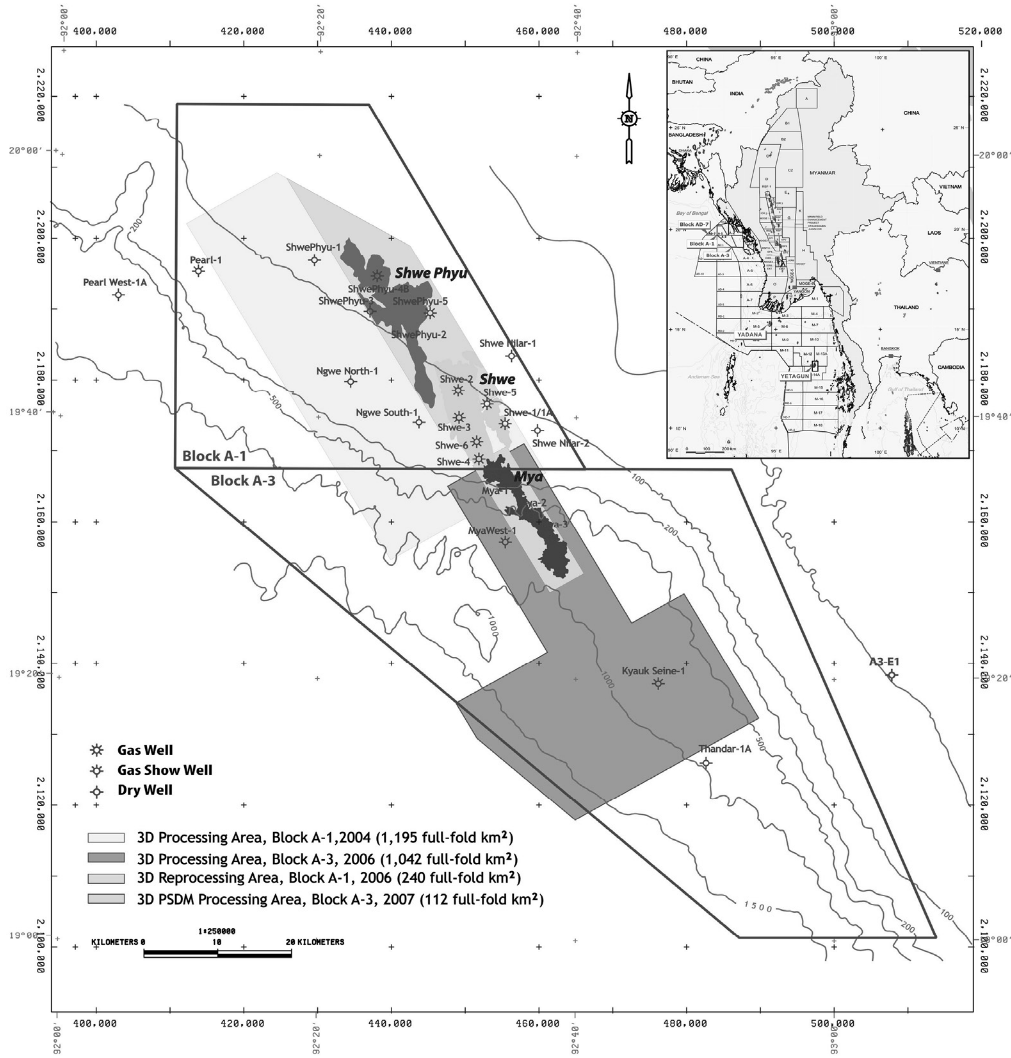

Fig. 1. Location map of the Shwe, Shwe Phyu and Mya fields.

2. INVERSION PROCESS

Traditionally, inversion has been applied to post-stack seismic data with the aim of extracting acoustic impedance only. Recently, inversion has been extended to pre-stack seismic data in order to extracting both P- and S-impedance. This allows the calculation of pore fluids. Another recent development is to use inversion results to directly predict lithologic parameters such as porosity and water saturation.

Post-stack seismic inversion transforms an input seismic volume into a P-impedance volume. Recently, Sparse Spike Inversion has been widely used as post-stack seismic inversion (Pendrel, 2006). It assumes that the actual reflectivity can be thought of as a series of large spikes embedded in a background of small spikes. It also assumes that only the large spikes are meaningful and finds the location of these large spikes by examining the seismic trace. Sparse Spike Inversion builds up the reflectivity sequence one spike at a time. Spikes are added iteratively until the trace is modeled accurately enough.

Conventional inversion using post-stack seismic data should not be applied to data with Amplitude versus Offset (AVO) effects because changes in Vp/Vs are not explicitly accounted for. To extend inversion to handle AVO data, pre-stack seismic data should be employed. There are several algorithms for the AVO inversion such as (1) elastic impedance inversion, (2) P- and S-impedance (Zp and Zs) inversion, (3) simultaneous inversion for Zp, Zs and density and so on. Simultaneous Inversion for Zp, Zs and density among these algorithms is popularly used as AVO inversion (Pendrel, 2007). This inverts for Zp, Zs and density using pre-stack seismic data or angle stacks as input. The benefit of this procedure is that it allows constraints to be imposed between these variables. This can stabilize the results and reduce the non-uniqueness problem.

Another recent inversion technique is Geostatistical Inversion which explicitly addresses the non-uniqueness problem by producing a large range of inversion results for a given input seismic volume, well log data and geostatistics (Pendrel, 2004). It allows direct inversion to rock, fluid and petrophysical properties of the reservoirs. It can be very powerful in separating individual lithologies and provides higher resolution models, which can be useful for identifying thin beds. Preprocessing such as dimming compensation and time alignment among angle stacks are applied to the seismic data for improving the final inversion results. The Markov-Chain Monte Carlo (MCMC) technique is employed as the inversion algorithm of Geostatistical Inversion process (Gilks et al., 1996). MCMC is a technique for obtaining a statistically correct random sample from a complex probability distribution, via incremental adjustments similar to those made by an optimization algorithm such as conjugate gradients. It is ideally suited to inversion problems because it can take both the seismic and the geostatistics into account, rigorously, all the way through the run. Though a single result can be deduced from deterministic inversion such as Sparse Spike Inversion and Simultaneous Inversion, multiple results are available using Geostatistical Inversion. Each of the results is consistent with the seismic data, and honors the expected continuity conditions, as constrained in the variograms. The output elastic properties should be P-Impedance, S-Impedance (or Vp/Vs) and density. After running Geostatistical Inversion, co-simulation would be performed to obtain petrophysical properties such as porosity and water saturation. These results are analyzed to give an estimate of the uncertainty in the result, along with the most probable result.

3. APPLICATION IN GAS FIELDS, OFFSHORE MYANMAR

In order to evaluate reservoir properties, inversion studies have been performed with the specific objectives for each stage such as exploration, appraisal and development period. In the early stage of the exploration period, simple inversion techniques are generally employed for the exploration and appraisal works. And then, Geostatistical Inversion technique is applied to the fields for the detailed characterization of the reservoir.

Between 2004 and 2006, a number of reservoir characterization studies had been performed over the Shwe, Shwe Phyu and Mya fields, offshore Myanmar. These reservoir characterization projects had been executed using basic Sparse Spike Inversion and advanced Simultaneous Inversion technologies. The results of the first Sparse Spike Inversion study using fast-track seismic data were concluded that it was not reliable because the results showed minimal difference from the amplitude maps. The other Sparse Spike Inversion study was completed in Shwe Phyu using the reprocessed 3D seismic data of which data quality was enhanced after reprocessing. In spite of the disappointing result in the inversion study in Shwe, the fluid type was correctly predicted at Shwe Phyu using Sparse Spike Inversion because the quality of the input data was enhanced greatly. The inversion study predicted the extension of the gas reservoirs to the west in Shwe Phyu and the result was used to deside the appraisal well locations as well.

The Simultaneous Inversion study was carried out in the Shwe and Mya fields in 2005 and 2007, respectively. However, it was difficult to predict the fluid type at the blind wells using the results of this inversion study. Especially, it was also proven that it is difficult to differentiate thinly-laminated gas reservoirs by inversion because the result of deterministic inversion was also limited to seismic resolution.

In order to prepare the field development plan for three gas fields, Geostatistical Inversion, the most recent technology, has been performed over the Shwe, Shwe Phyu and Mya fields from 2008 to 2009. Prior to carrying out inversion process, several preprocessing such as dimming compensation and time alignment were applied to the input seismic. The dimming compensation was performed at the dimmed area affected by the shallow geology and rugose water bottom. Figure 2 shows the dimming effects in the Mya field. In order to apply AVO effects to the field precisely, the time alignment had been performed for the all angle stacks of each field. Even though the original seismic data set was already flattened, the time alignment should be applied to obtain the best inversion result.

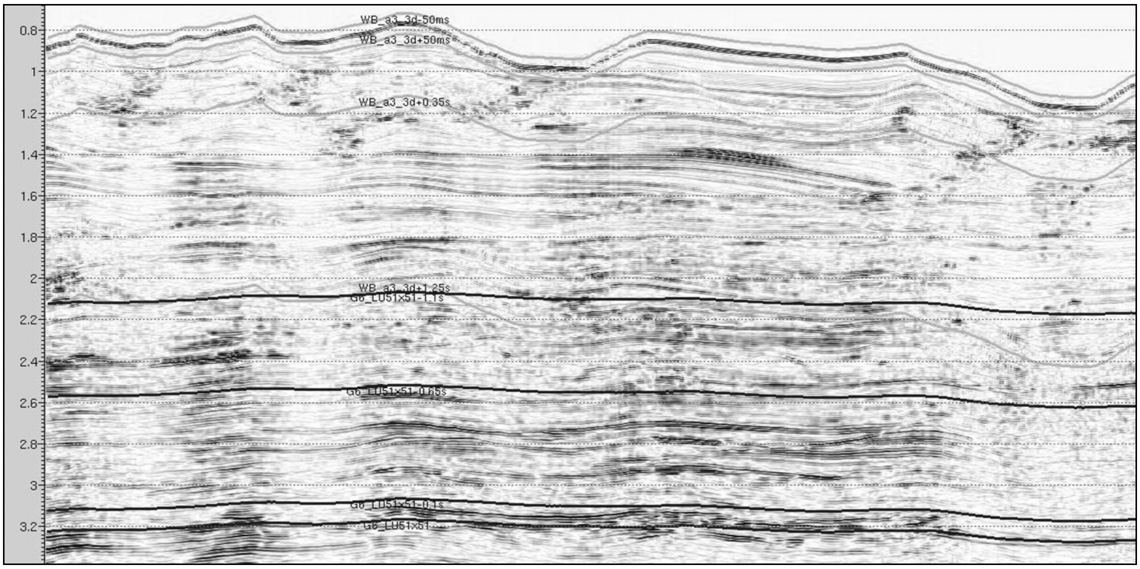

Fig. 2. Cross section showing dimming area in the Mya field.

The number of realization for the Geostatistical Inversion process was 15, and the co-simulation for petrophysical properties was performed 3 times based on each of the 15 realizations of Geostatistical Inversion in this study. All of the realizations are a little different from each other but they were consistent with the seismic and well data (see Fig. 3). The results obtained from the multi-realization were useful to for the reservoir uncertainty evaluation.

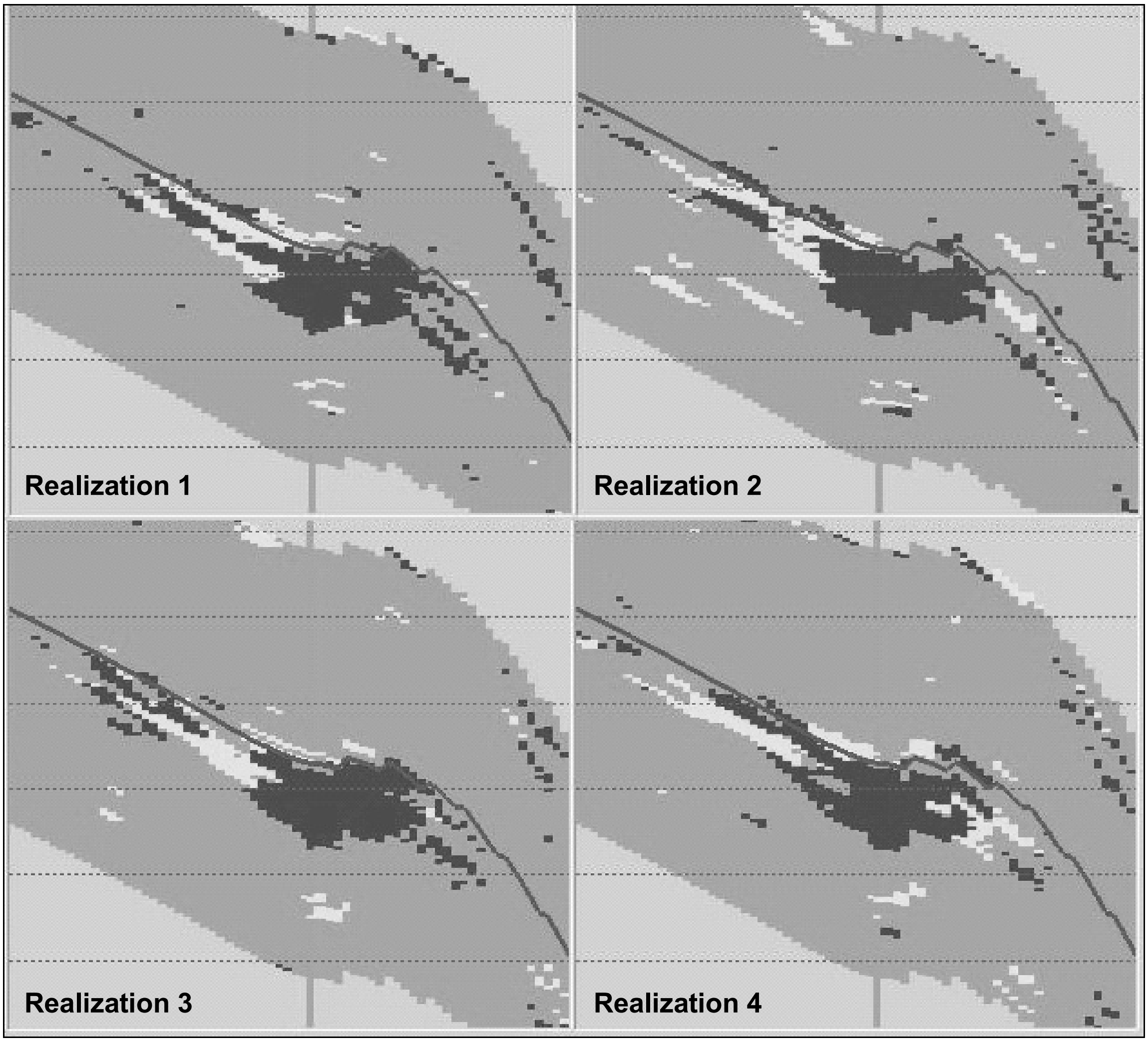

Fig. 3. Realizations of Geostatistical Inversion.

Figure 4 compares the vertical resolutions of Geostatistical Inversion and Simultaneous Inversion in time section. Because the high resolution results can be obtained from Geostatistical Inversion, the meaningful vertical as well as spatial properties can be applied to the geological modeling. Even though thin layers can be resolved by the Geostatistical Inversion, however, it was difficult to capture very thin layers defined in the petrophysical interpretation below 4 m.

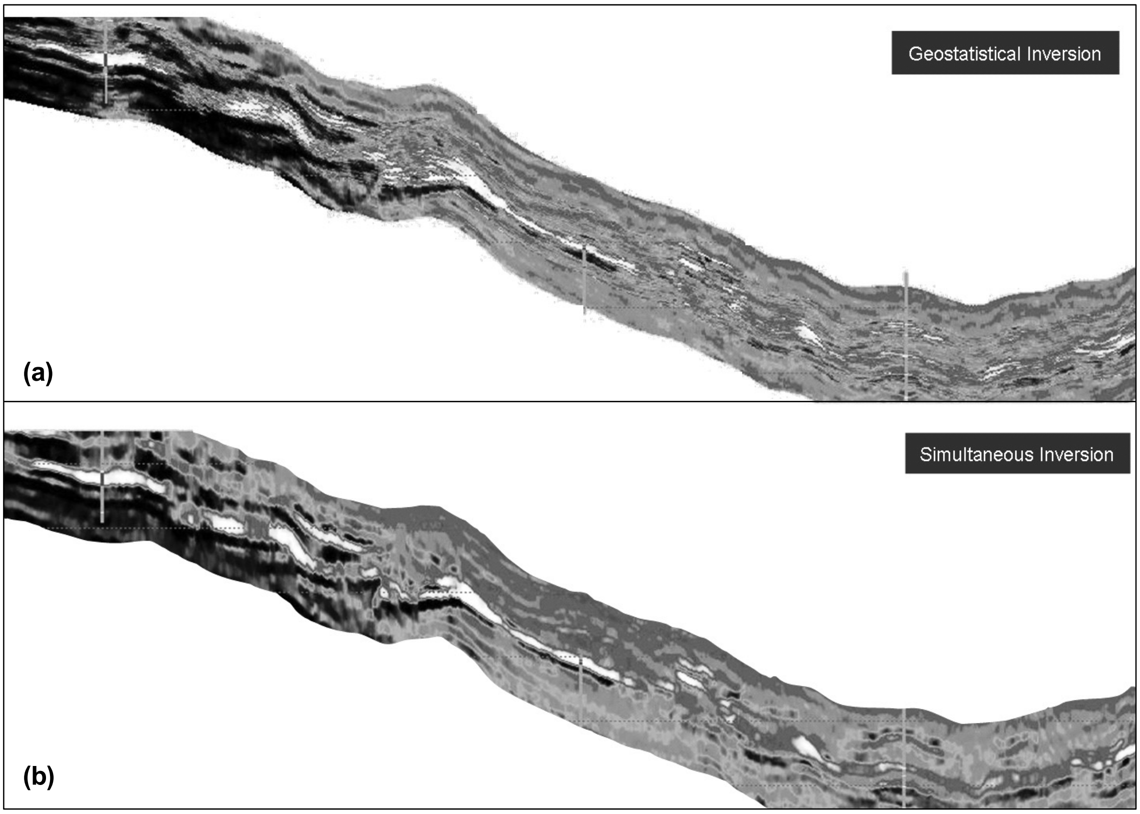

Fig. 4. Comparison between (a) Geostatistical Inversion and (b) Simultaneous Inversion.

The time sections for the P-impedance and effective porosity in the Shwe field are presented in Figure 5. For the attribute analysis, the RMS values of the main attributes obtained from Geostatistical Inversion had been extracted from each reservoir interval. Figure 6 shows an example of the extracted RMS P-impedance and effective porosity for the G5.2 reservoir of the Shwe field. The field boundary can be clearly defined from the attribute map presented in the figure. Therefore, the P-impedance and effective porosity maps were mainly used for the confirmation and revision of the reservoir boundaries. The revised boundaries had been applied to the geological modeling for the field development plan.

The results of Geostatistical Inversion are good to be used for geological modeling. The main advantages to perform the geological modeling based on the Geostatistical Inversion results are listed as below.

- Application of vertical trend from the high resolution GI results
- Uncertainty evaluation using multi-realization
- Inference of geological body extent
- Fine tuning based on well data

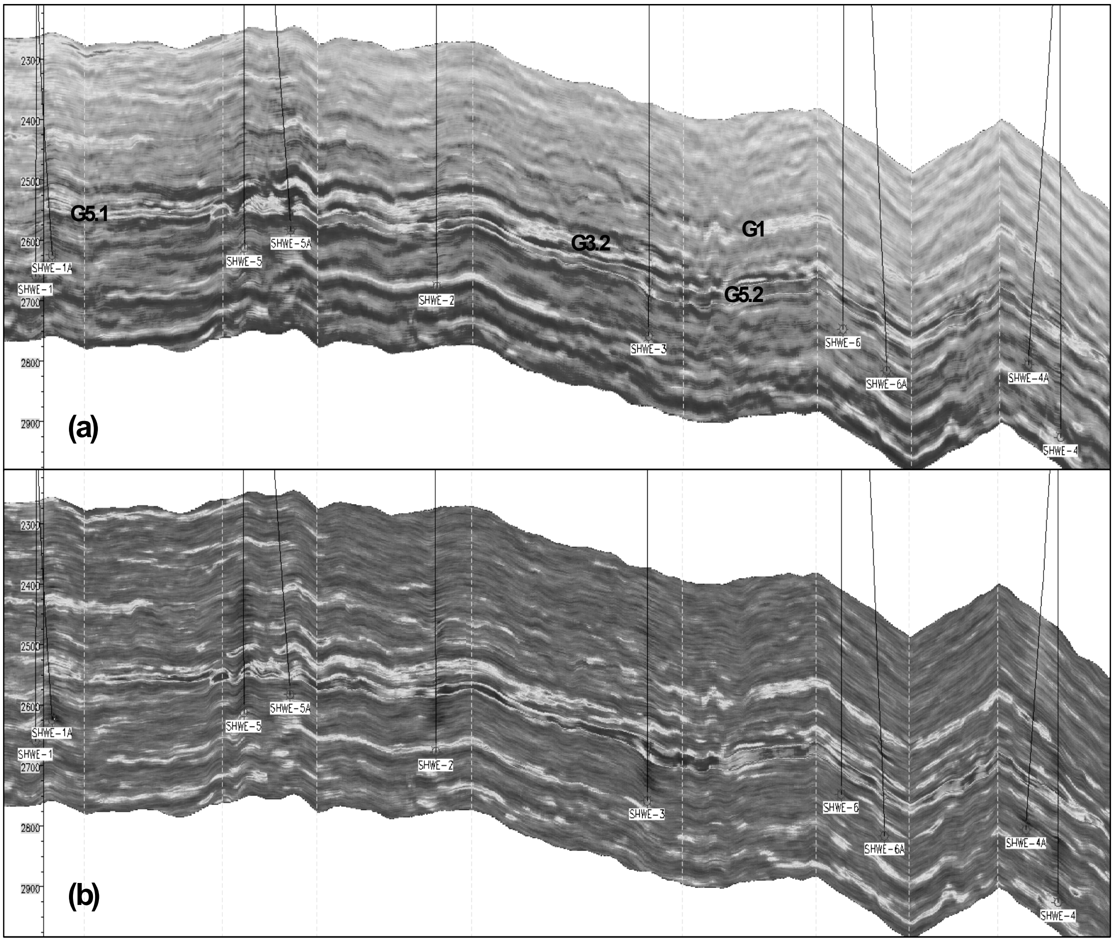

Fig. 5. Time sections for (a) P-impedance and (b) effective porosity in the Shwe field.

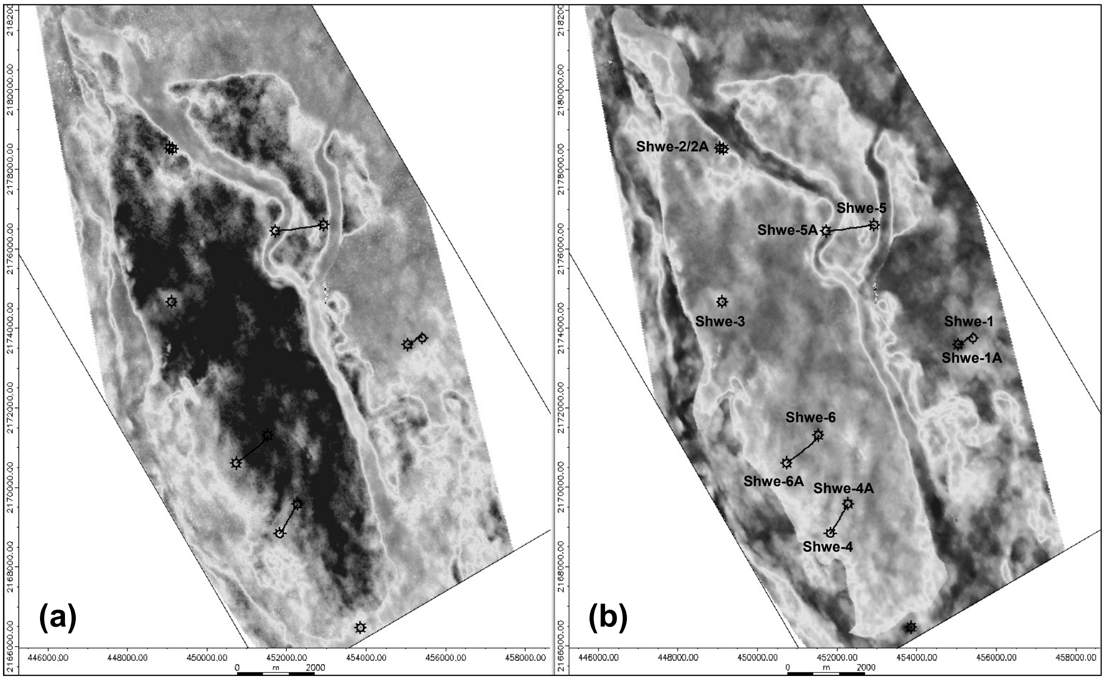

Fig. 6. (a) RMS P-impedance and (b) effective porosity maps in the Shwe field.

These are reasons to perform the geological modeling for the gas fields based on the Geostatistical Inversion results. Especially, the high resolution results are very useful to the geological modeling because the vertical trend in the reservoir interval can be applied to modeling. Before using the results of Geostatistical Inversion, just 2D spatial trends were applied to the geological modeling because the vertical resolution of the deterministic inversion results was too low to be used (see also Fig. 4). In addition, the result of Geostatistical Inversion is well matched with the geological concept because the vertical properties observed in the well data can be applied to the Geostatistical Inversion process. Especially, in the Mya field, the fining upward trend was observed in the Mya wells and it was applied to the Geostatistical Inversion study.

4. CONCLUSIONS

Reservoir characterization for the gas field is important for the development plan. Several inversion processes have been applied to the reservoir characterization of the Shwe, Shwe Phyu and Mya fields, offshore Myanmar. The quality of the input data is very important because it can affect the inversion result. Preprocessing such as amplitude compensation and time alignment of the seismic data are also essential for the inversion result. The results of the Geostatistical Inversion and co-simulation were used for the final reservoir characterization for Shwe, Shwe Phyu and Mya. They were also applied to the geological modeling for the reservoirs of each field, and the modeling results were satisfactory for the field development plan.

5. ACKNOWLEDGEMENT

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