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Prediction of Fine Reservoirs Interbedded with Thin Coals

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Summary

Prediction for fine reservoir sands in the presence of coal beds through seismic reservoir characterization is hugely difficult, especially when the thin coal beds are interbedded with the sands. The observed seismic characteristics might not reflect the real characteristics of the reservoirs but rather a complex reflection interference of coals and sands that has a direct relation to the seismic resolution. In order to use the seismic characteristics to support the design of new development wells, and ensure successful drilling results, the distribution of the reservoir sands would need to be accurately predicted.

Introduction

Prediction for fine reservoir sands in the presence of coal beds through seismic reservoir characterization is hugely difficult, especially when the thin coal beds are interbedded with the sands. The observed seismic characteristics might not reflect the real characteristics of the reservoirs but rather a complex reflection interference of coals and sands that has a direct relation to the seismic resolution. In order to use the seismic characteristics to support the design of new development wells, and ensure successful drilling results, the distribution of the reservoir sands would need to be accurately predicted.

Key Technology

Based on the geological problems and technical challenges, key technologies and workflows employed in the seismic inversion study include:

- Seismic petrophysics and rock physics modeling
- Post-stack geostatistical inversion
- Seismic forward modeling and analysis
- Pre-stack geostatistical inversion constrained by coals

First of all, an integrated and iterative seismic petrophysics and rock physics modeling workflow was used to build the elastic parameter characteristic and relationship for the coals and reservoir sands. Secondly, the coal beds in 3D were predicted through post-stack geostatistical inversion. Thirdly, seismic forward modeling and analysis workflow was performed to understand how the reservoir prediction is influenced by the interbedded thin coals. Finally, pre-stack geostatistical inversion (Sams, et al., 2011) was run using a 3D distribution of coal facies predicted from the post-stack geostatistical inversion to achieve an accurate prediction for the3D distribution of reservoir facies (Jarvis, 2006). These technologies coupled with extensive quality controls produced robust and accurate final prediction results.

Case Study

The research area is located in East China Sea. The target reservoir is deposited in delta environment. It has been buried to depths from 3500m to 4700m. The porosity of the gas sands ranges from 8% to 15%. However, abundance thin coal beds (less than 1.5m) often occur interbedded with the reservoirs resulting in complex seismic reflections gravely hampers reservoir prediction.

Rock physics characteristic and seismic data analysis

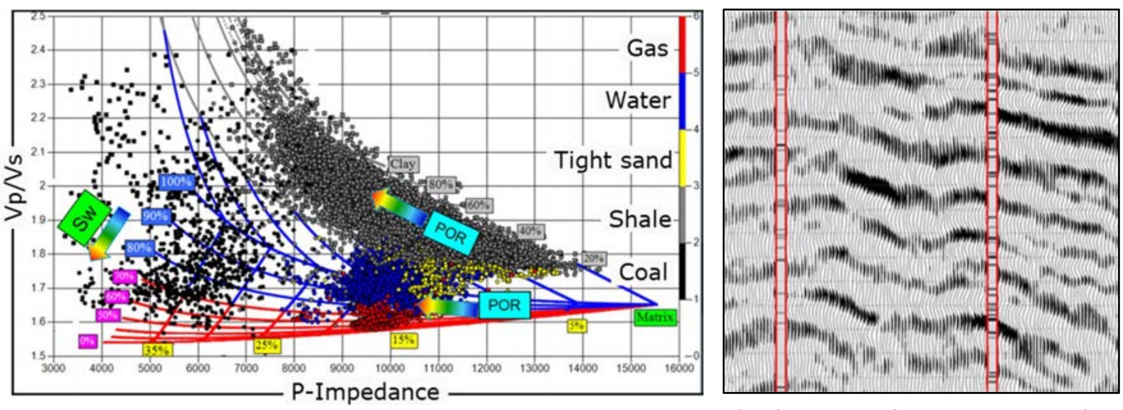

Figure 1 *Rock physics modeling results and rock physics template for facies and fluids analysis (left). Seismic section through two representative wells illustrating the seismic reflections of thin interbedded coal beds (right).*

The results of seismic petrophysics and rock physics modeling are shown in the left picture of Figure 1. A rock physics template was overlaid for facies and fluids interpretation. Each facies has obvious distribution in the elastic parameter domain as well as reservoir (petrophysical) parameter domain. Coal shows very low P-Impedance value, and could easily be distinguished from all other facies. On the full stack seismic volume, the thin interbedded coals exhibit strong seismic reflections (right picture in Figure 1) which mean they could be well predicted through post-stack seismic inversion. Shale, Water sand, Gas sand and Tight sand show overlap based on P-Impedance alone, but their separation becomes distinctive when Vp/Vs is used in concert. Shale shows the highest Vp/Vs value, Water sand and Tight sand show average Vp/Vs, and Gas sand has the lowest Vp/Vs value. Thus, P-Impedance and Vp/Vs should be used jointly for successful quantitative interpretation of the target reservoirs which means pre-stack or AVO/AVA inversion workflow is required.

Post-stack geostatistical inversion

Based on the rock physics modeling and seismic analysis for coals, post-stack geostatistical inversion was applied in this study to determine the 3D distribution of the thin interbedded coal beds. Figure 2 shows the inverted P-Impedance comparison between deterministic inversion and post-stack geostatistical inversion. From the deterministic inversion, coal beds are captured in the low P-Impedance but the resolution is too low and not able to identify the individual thin coal beds. From the post-stack geostatistical inversion, the locations and thickness of the thin interbedded coals with the lowest P-Impedance values compared to surrounding facies have been well captured, and exhibit excellent match to the well data. The distribution of the predicted coal beds in 3D through the post-stack geostatistical inversion is shown in the right picture in Figure 2.

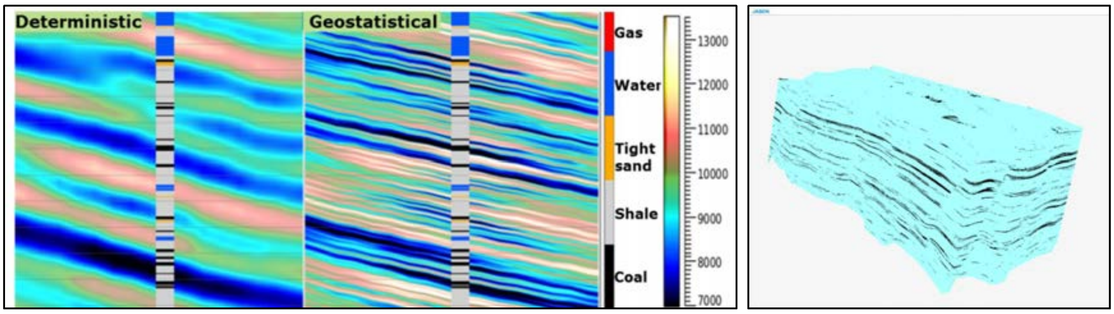

Figure 2 *Comparison of inverted P-Impedance from deterministic inversion (left) versus geostatistical inversion (middle). 3D distribution of coal beds (black color) determined from post-stack geostatistical inversion (right).*

Seismic forward modeling and analysis

In this study area, the reservoir development is very complex below the thin interbedded coal beds. It could be (1) a single thick sand bed (more than λ/8); (2) a single thin sand bed (less than λ/8); or (3) multiple thin sand beds. So, it is very important to know the influence of the interbedded coals with the different sand depositional characteristics to reservoir prediction. This understanding could improve quantitative interpretation performed on the seismic inversion results. The three scenarios of reservoir sand development were forward modeled and presented in Figure 3. The top picture in Figure 3 shows the seismic forward modeling for a single sand bed with varying thickness (5m to 40m) deposited below five 1m coal beds in a shale background. The tuning thickness (λ/4) for this seismic dataset is about 40m. Through analysis of the forward model and inverted results, the top and base of the sand have obvious seismic reflection when the sand thickness is more than 20m (λ/8), and the inverted bandpass Vp/Vs predicts correctly the thickness and Vp/Vs value of the sand. When the sand thickness is less than 20m (λ/8), the seismic reflections at the top and base of the sand become ambiguous, and the inverted bandpass Vp/Vs over predicts the thickness but under predicts the Vp/Vs value of the sand. The bottom picture of Figure 3 shows the seismic forward modeling for varying number of 2m sand bed (2 to 5) deposited below five 1m coal beds in a shale background. Through analysis of the forward model and inverted results, the seismic reflections at the top and base of the group of interbedded sands are ambiguous, and the inverted bandpass Vp/Vs over predicts the thickness but under predicts the Vp/Vs value of the sands for all cases.

Seismic forward modeling and analysis prove that there would be no interference from interbedded coals when the sand thickness is more than λ/8 (20m) for reservoir prediction through seismic inversion. On the contrary, reservoir prediction through seismic inversion would be affected by the interbedded coals when sand thickness is less than λ/8 (20m) or when the sand is deposited as thin interbedded sand beds below the coals. Thus, pre-stack geostatistical inversion that attempts to resolve thin beds was recommended in the study.

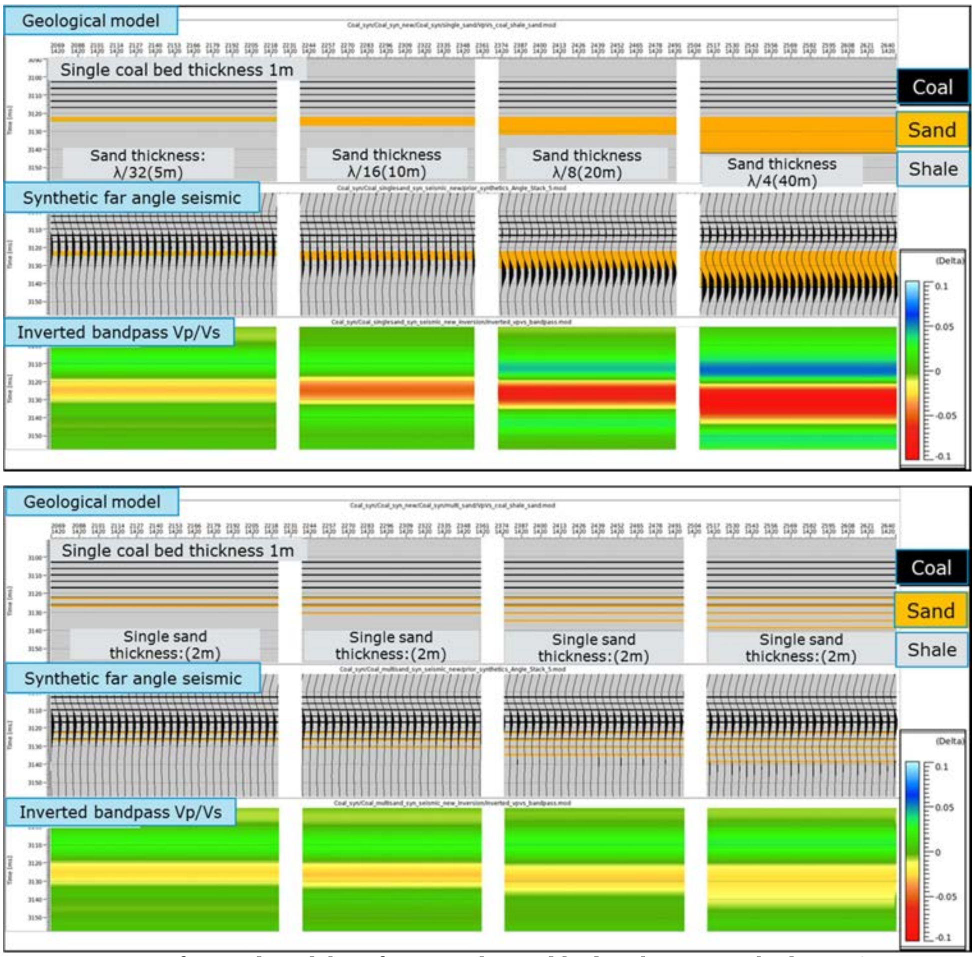

Figure 3 *Top: Seismic forward modeling for a single sand bed with varying thickness (5m to 40m) deposited below five 1m coal beds. Bottom: Seismic forward modeling for varying number of 2m sand bed (2 to 5) deposited below five 1m coal beds. The background facies is shale. The expected bandpass Vp/Vs value for the sand is -0.1(red color).*

Pre-stack geostatistical inversion constrained by coals

In this study, since full stack seismic is more robust in predicting the vertical and lateral distribution of the thin interbedded coals through post-stack geostatistical inversion workflow, the resultant 3D coal distribution volume could be used as input 3D coal facies proportion model in the subsequent pre-stack geostatistical inversion workflow. The facies proportions for Porous sand and Shale were computed based on the overall proportion from well facies logs, and they are taken as constant proportion per solid model layer. At the samples where coal exists, the Porous sand and Shale proportion is calculated as one minus coal proportion. Figure 4 shows the final computed 3D facies proportion models for Porous sand, Shale and Coal. These three facies proportion models were used as prior facies probabilities in the pre-stack geostatistical inversion process to guide a meaningful and precise prediction of facies in the final inverted results.

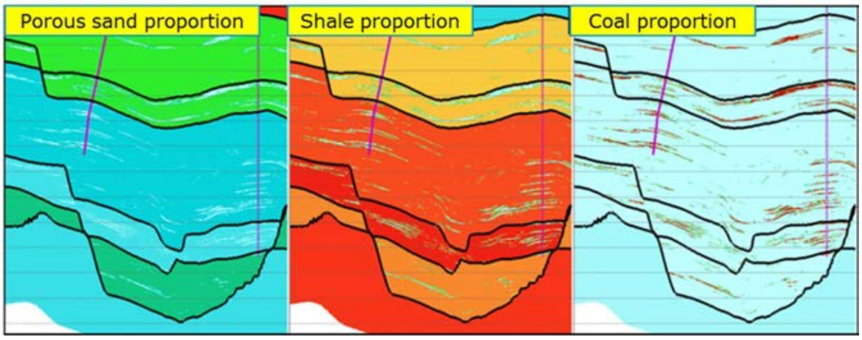

***Figure 4** 3D facies probability models used as input in the pre-stack geostatistical inversion workflow (high probability in warm colors).*

Through the coal constrained pre-stack geostatistical inversion, the precision of prediction for both reservoir sands and coals are significantly improved compared to the deterministic inversion (Figure 5). A comparison of porous sand probability between these two inversion methods shows that pre-stack geostatistical inversion produces much higher precision in predicting the vertical positioning and thickness of the porous sands.

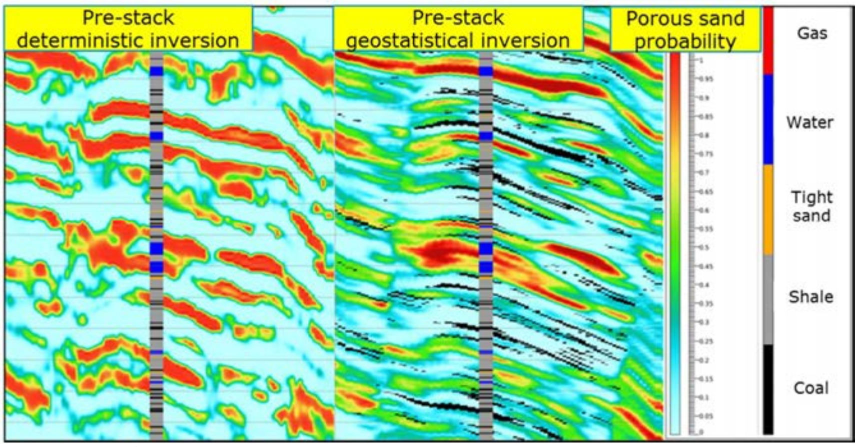

***Figure 5** Comparison of predicted porous sand probability (high probability in warm colors) between pre-stack deterministic inversion (left) and geostatistical inversion (right).*

Conclusions

The technologies and workflows presented in this case study have achieved excellent success in this area. Seven development wells have been drilled based on the pre-stack geostatistical inversion results with effectively 90% match for thirteen targeted thin gas sands. These technologies and workflows could also be applied in other fields and basins with similar geology to support planning of drilling locations, improve drilling success and production efficiency.

References

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Sams, M., Millar, I., Satriawan, W., Saussus, D., and Bhattacharyya, S., [2011]. Integration of geology and geophysics through geostatistical inversion: a case study. *First Break*, **29**.