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Comparison of Deterministic and Geostatistical Inversion Results - A Case Study for a Gas-saturated Reservoirs with Coals

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SUMMARY

In this paper, we discuss a comparison of deterministic and geostatistical inversion approaches to reservoir characterization of a complex gas-saturated clastic reservoir with thin coal beds. This reservoir type is characterized by high acoustic contrasts which present challenges for inversion techniques. To overcome these challenges in deterministic inversion, a methodology was applied to update the low frequency model in an iterative manner. This method improves the accuracy of elastic properties prediction which was verified with data from 28 newly drilled wells. Furthermore, it proves that for quantitative reservoir characterization, the application of AVO/AVA geostatistical inversion is recommended.

Introduction

Reservoir characterization is based on results from seismic inversion. There are many different algorithms for seismic inversion, but each of them implies different subsurface structures and elastic properties and therefore, has its own limitations. Quantitative reconstruction of elastic properties can become complicated and selection of an appropriate inversion method is crucial. In this paper a comparison of two types of simultaneous AVO/AVA seismic inversion will be shown: deterministic inversion based on Constrained Sparse Spike Inversion, (CSSI algorithm) and geostatistical inversion based on Markov Chain Monte Carlo, (MCMC, algorithm). The inversion results will be analyzed using the accuracy of the reconstruction of the elastic properties.
There are many ways to verify the quality of seismic inversion results, but arguably the best approach is comparison of the reservoir model with blind wells either existing or newly drilled wells. Several of these new wells were drilled based on previously obtained inversion results that proved the predicted reservoir distribution.

Rock physics

Rock Physics Modelling (RPM) of the elastic properties was carried out within the target interval to achieve a reliable seismic tie and obtain elastic properties without the influence of borehole conditions, such as wash-outs within shale and coal intervals. Cross-plots of the elastic properties after rock physics modelling colored with lithology and saturation are shown in Figure 1. The target interval is represented by thin-bedded gas-saturated reservoirs (the layer thickness is often about 2-4 meters) in a shale background with high coal content. Coal beds and gas-saturated reservoirs are characterized by lower P-impedance values. Since there is considerable overlap in P-impedance, they can only be separated by using an additional elastic parameter such as the Vp/Vs ratio. Gas-saturated reservoirs are characterized by a lower Vp/Vs ratio than coal (Figure 1). The cross-plots show that a reliable discrimination of the gas reservoirs from non-reservoir facies can be achieved by a simultaneous AVO/AVA inversion. Unfortunately, the prediction of brine reservoirs from inversion results is not possible due to a significant overlap of its elastic properties with non-reservoirs facies.

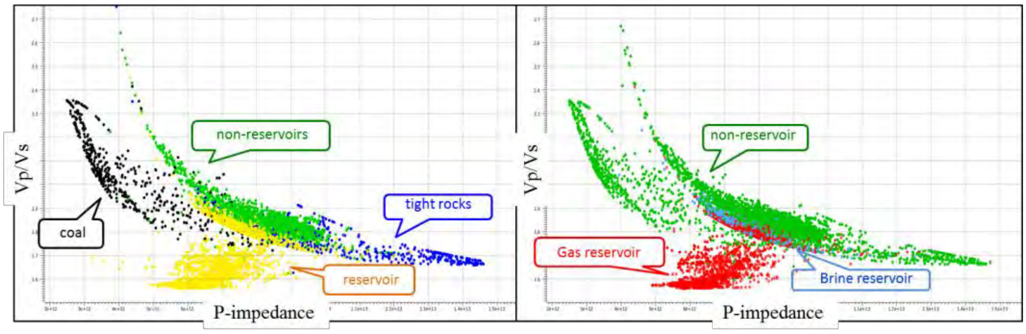

***Figure 1** P-impedance versus Vp/Vs cross-plots colored with a lithology flag (left) and a saturation flag (right)*

Deterministic inversion

Deterministic simultaneous AVO inversion based on the CSSI algorithm has been performed by parameterization in P-impedance, Vp/Vs ratio and density. This algorithm minimizes the number of reflections during the seismic inversion process giving a result that is more acceptable from a geological point of view In most cases, the subsurface is characterized by small elastic contrasts.
However, CSSI inversion has its own strengths and weaknesses. The advantage is that well data are not used directly in the elastic properties calculations. Reconstruction of the elastic properties within the seismic bandwidth comes purely from seismic data. A low frequency part is often constructed by involving well data (P- and S- waves, density logs). This low frequency model is not a starting model for the inversion; therefore it is a supplementary component to obtain the absolute rather than relative values of elastic properties.
High contrast layers have a response in the seismic band and also an imprint on the low frequency trend model. The well control is not optimal to describe the lateral variability of the trend. In this

situation it is necessary to use an approach of iterative updating of low frequency trend models. For this purpose the first stage low frequency models were constructed using the wells, whereby for all gas-saturated reservoir beds fluid substitution to brine was performed and within the coal beds elastic properties values were changed to the values of shales. The first pass inverted P-impedance and Vp/Vs volumes were analyzed to identify the gas-saturated reservoirs and coal geobodies.
As a next step, the trend models used for the first pass of inversion were updated within the geobodies of gas-saturated reservoirs (Jarvis, 2006) and coal beds: the values of P-impedance, Vp/Vs and density were replaced by the mean values of corresponding elastic properties for each considered lithotype. For intervals where individual gas reservoirs appeared to be resolved by the inversion, the tops and bases of the units were interpreted. The lateral variability of the elastic properties for these units was captured by measuring the elastic contrasts over the interpreted horizons, a method first introduced by Mesdag et al. (2010). The second pass inversion was calculated using the adjusted low frequency models (Figure 2). At first glance it seems that the vertical resolution decreased after the second iteration, but this is deceptive. The second pass reduces the side-lobe effects and the dimming at the middle parts of the thicker bodies. The key benefit of updating the low frequency models is that it improves the match of the elastic contrasts after the second iteration to the wells (Figure 2). As a result, the fit of the interpreted lithology to the wells is more superior. This approach increases the accuracy of the inverted elastic properties from deterministic inversion in high-contrast subsurface.

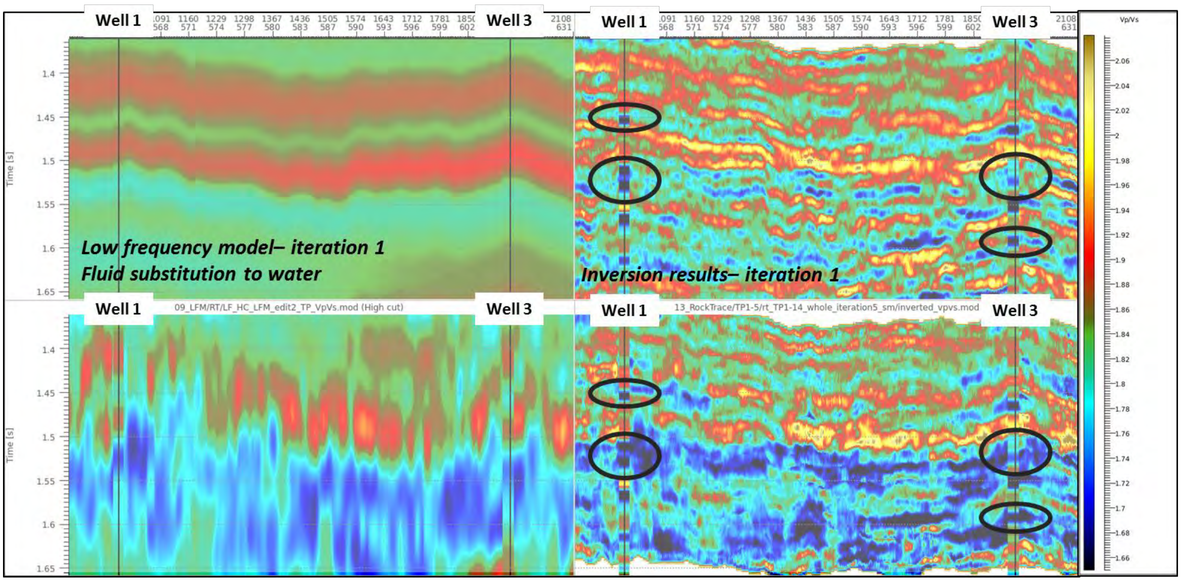

Figure 2 *Comparison of low frequency models (left) and simultaneous inversion results (right) for the first and the second iterations (black ovals indicate zones where quality of elastic properties reconstruction was significantly increased after low frequency model updating).*

Geostatistical inversion

The idea underlying our geostatistical inversion is rather simple: it is a combination of Bayesian approach and a stochastic MCMC algorithm. Geostatistical inversion can be applied in any geological condition and suffers less from typical limitations of the deterministic inversion: the limited vertical seismic resolution and the complex solution for high contrast layers. Multiple plausible models of elastic and discrete properties are created using sets of parameters (Pdfs, variograms, proportions, vertical or lateral trends, etc. (Sams et al., 2011)), while minimizing the mismatch with the seismic data. In this case study, 30 realizations of detailed reservoir distribution were calculated. Each realization set contains lithology and elastic properties (P-impedance, Vp/Vs ratio, density, etc.).
The main challenge in parameterizing geostatistical inversion is to provide the most accurate description of the input data (S/N level, pdfs for each lithotype, geological trends, etc.). Some of the critical parameters are angle/offset dependent wavelets and signal-to-noise ratio for each angle/offset stack. Reliable determination of these parameters can only be done with the understanding from the results of deterministic inversion. This is why carrying out deterministic inversion is an important and necessary step before performing geostatistical inversion.

Figure 3 shows a comparison of deterministic and unconstrained geostatistical inversion results. Unconstrained means that elastic property logs were not used to constrain the geostatistical inversion. Geostatistical inversion allows more precise reconstruction of elastic properties in the case where presence of strong elastic contrasts exists. Therefore, predicted reservoir properties from geostatistical inversion match the drilling data much better than the results from the deterministic inversion.

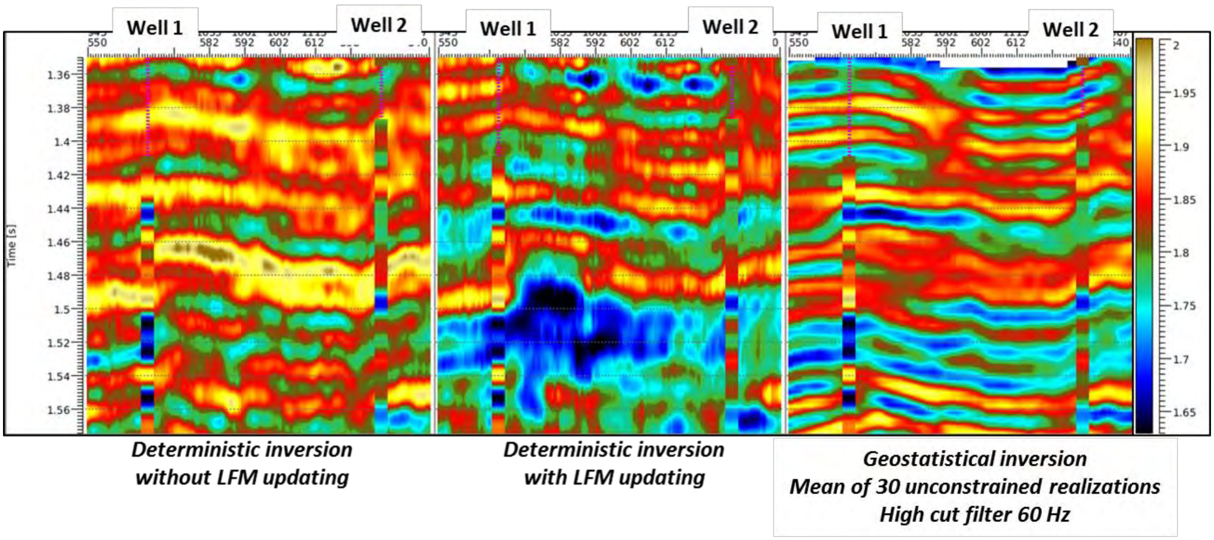

Figure 3 Sections of inverted Vp/Vs ratio volumes from different seismic inversion techniques.

Verification of deterministic and geostatistical inversion results with new wells

After obtaining the results of reservoir characterization based on deterministic inversion with an updated low frequency model, 28 new wells were drilled based on inversion results within the study area and the accuracy of prediction was estimated for all these wells in 17 target intervals. The results are shown in Figure 4A. Generally speaking, the correlation between the inversion result and well data is very good. A detailed comparison of well data with the probabilistic interpretation of the deterministic inversion result (gas reservoir probability volume) is shown in Figure 4B.

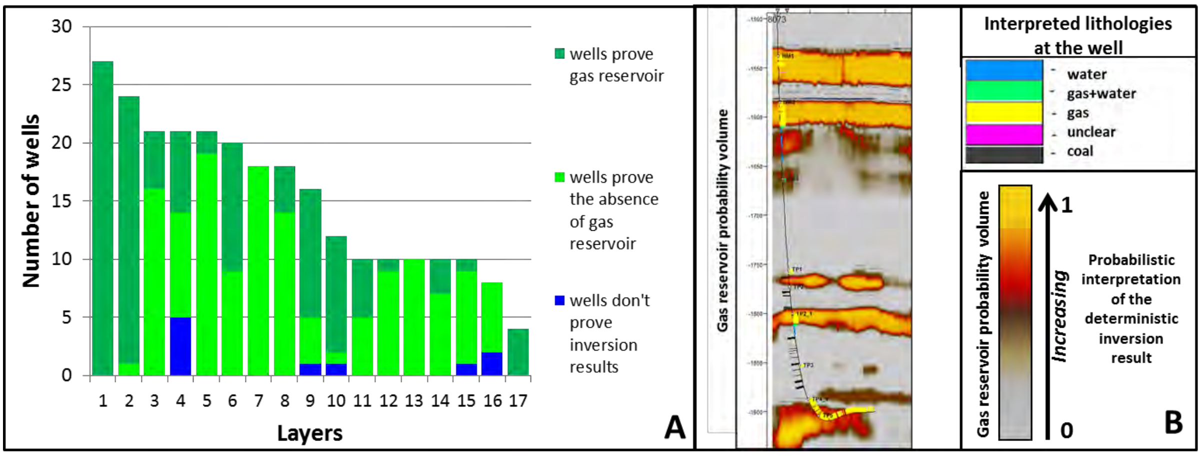

Figure 4 *Verification of interpreted reservoir geobodies from deterministic inversion with newly drilled wells. (A: Overall statistics for all wells at each target interval; B: Section of gas reservoir probability volume overlaid with interpreted lithology at one of the new well locations).*

Due to more realistic controls of the model building in geostatistical inversion, lithological variations between verticallystacked high contrasting layers are better resolved than with deterministic inversion. Geostatistical inversion improves the reconstruction of elastic properties of thin beds because a vertically detailed grid is used for this modelling and, as a result, the predicted reservoir distribution will be more accurate (Figure 5). In addition, the uncertainty of reservoir definition from geostatistical inversion is smaller than the uncertainty of deterministic inversion for thinly layered sections (Sams and Saussus, 2010). For this study, geostatistical inversion was performed in one part of the area and for a few target intervals. So the amount of data is not sufficient to make the same comparison table as was done for deterministic inversion. Figure 5 shows a comparison of lithology realization from geostatistical inversion that captured reservoir and coal geobodies after probabilistic interpretation of deterministic inversion. The geostatistical inversion is not constrained by wells. It can be observed that in the case of a thinly layered section with high elastic contrasts, deterministic inversion provides a more general description of reservoir geobodies distribution, whereas the outcome of the geostatistical inversion reconstructs a detailed subsurface composition.

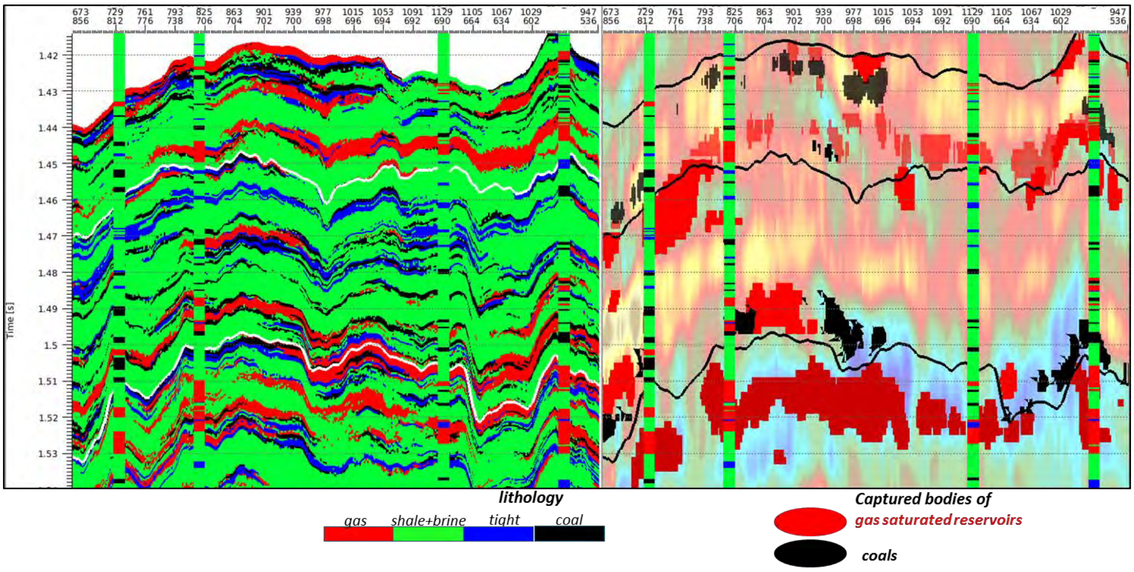

Figure 5 *Comparison of one unconstrained lithology realization from geostatistical inversion (left) and captured reservoir and coal geobodies after deterministic inversion with updated low frequency model (right).*

Conclusions

Geostatistical inversion is recommended for quantitative reservoir characterization and accurate reservoir models. In the context of a complex gas-saturated clastic reservoir with thin coal beds, we have shown that geostatistical inversion provides lithological variations and elastic properties distributions with a higher level of detail than the deterministic inversion.Geostatistical inversion results can thus be used for the refinement of the geological model as well as planning and optimizing the production well pattern.

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