23826

Highly Detailed Reservoir Characterization of Tight Thin Sandstone through Geostatistical Inversion in a Gas Field China

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SUMMARY

A gas field, China, the target reservoirs are mainly delta front depositions, which are tight, thin and below the tuning thickness. In order to characterise the thin effective reservoir and porosity distribution in this field, a geostatistical inversion and co-simulation were performed. Using geostatistical inversion technology we can integrate the information of well logs, geological constraints, geostatistical parameters and seismic data to create multiple high resolution realizations, resulting in highly detailed elastic volumes of P-Impedance, Vp/Vs, density, as well as lithofacies distribution and the co-simulated porosity. The combination analysis of the results can be used to propose new drilling locations. New well data shows the validity of this technology, maximum solve the problem of the low porosity, low permeability and thin reservoir.

Introduction

Seismic data is band limited and has a limited vertical resolution. In the case of thin reservoir units seismic may not detect or resolve the geology. Geostatisitical inversion can improve the resolution and provide directly attributes for reservoir model filling by combining several data. We recently applied this technology on a Chinese gas field. The main pay interval is characterised by marine deposits. A secondary target interval is Xujiahe Triassic formation deposited in deltaic environment. Xu2, Xu4, Xu6 intervals, are mainly delta front depositions and recent drillings have proven the hydrocarbon potential.

Xujiahe formation is characterised by well-developed sand but effective reservoirs are very thin and both porosity and permeability are low, almost all sand units are below seismic tuning thickness, so seismic alone cannot characterise reservoir. In order to characterise the thin effective reservoir and porosity distribution in this field, a geostatistical inversion and co-simulation were performed. Using geostatistical inversion technology we can integrate the information of well logs, geological constraints, geostatistical parameters and seismic data to create multiple high resolution realizations, resulting in highly detailed elastic volumes of P-Impedance, Vp/Vs, density, as well as lithofacies distribution and the co-simulated porosity. The combined analysis of inversion results, lithology distribution and porosity has provided an estimate of effective reservoir thickness used to propose new drilling locations.

Methodology

Geostatistical inversion combines Bayesian inference with a Markov Chain Monte Carlo sampling algorithm to produce equally probable realizations of the lithofacies distribution, elastic property (Contreras *et al.*, 2005, Close *et al.*, 2011). According to the prior information such as the rock physics template, it can guide to construct probability density functions (PDF) for each lithofacies defined over the elastic parameters (P-Impedance, Vp/Vs and density). Then combine all the PDFs to yield a Bayesian posterior distribution over 3D reservoir property and lithology volume.

The next step is to use a customized Markov Chain Monte Carlo algorithm to obtain a fair sample of realizations from the PDFs. A realization consists of each reservoir elastic properties and of lithology in a high resolution grid that honours all of input data (well logs, seismic data, geology, etc.)

Porosity can be estimated using co-simulation process for each realization. The realisations are then ranked in term of mean, max, min and standard deviation for each continuous property: P-Impedance, Vp/Vs, density and probability volumes of lithofacies.

Finally we can use these results to analysis the studied area's reservoir characteristics such as sand thickness, effective sand thickness, mean porosity *et al*.

Case study

This area structure is north low and south high, fault orientation is N-W. It is a typical composite trap of structure and lithology. The main studied reservoirs are Xu2, Xu4 and Xu6 intervals in Xujiahe formation, all are sand containing thin shale sand is well developed but effective reservoir is thin ranging from 1 to 16 meters, below $\lambda/8$ whichby tuning thickness analysis is 16 meters. The effective porosity is ranging between 0.14%~7.84%, permeability is 0.01~15.83MD, as mentioned earlier, these sands have very low porosity and low permeability. Xu2 interval mean porosity and permeability are 2.56%, $0.0446 \times 10^{-3}um^2$, respectively, for Xu4 and Xu6's porosity is 1.97%, 1.52%, respectively, and permeability is $0.0306 \times 10^{-3}um^2$, $0.0343 \times 10^{-3}um^2$, respectively.

The objective of this study is to find the effective reservoir by mapping porosity distribution. According to the statistical results of the actual well gas testing and the productions, we have divided the lithology into 5 main lithotypes, coal, shale, tight sand, the first class sand (I sand), the second class sand (II sand). Sand I has better physical properties with effective porosity above 4%, sand II has an effective porosity between 2.5%~4%. Such tight sand has no production with effective porosity below 2.5%, detail definition are listed in Table 1. VDCL represents the content of clay, PHIE represents the effective porosity. From the rock physics template (Figure 1), we can see geology is sensitive to elastic parameters: P-Impedance and Vp/Vs ratio. A Vp/Vs ratio above 1.75 mainly related to shale. Lower values indicate sand. Sand distribution could be predicted using pre-stack inversion if seismic resolution was above tuning thickness. Therefor we applied geostatistical inversion to characterise thin reservoir interval.

Lithology		parameters
Shale		VDCL>=0.3
Sand	Tight sand	VDCL<0.3 and PHIE<2.5%
	II sand	VDCL<0.3 and4%>PHIE>=2.5%
	I sand	VDCL<0.3 and PHIE>=4%

Table 1: *evaluation standard of Xujiahe formation*

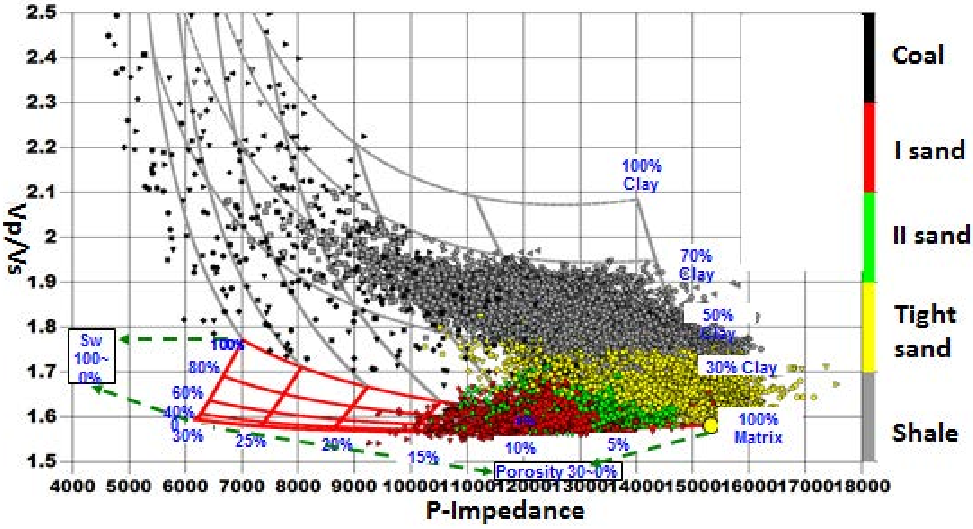

Figure 1 *the cross-plot of P-Impedance versus Vp/Vs ratio, the colour dots grey, yellow, green, red and black represent the shale, tight sand, II sand, I sand and coal respectively. In this template P-Impedance is measured and Vp/Vs ratio is forward modelling.*

Before running the geostatistical inversion, quality control of seismic data (amplitude, frequency, footprints, etc) is performed and wavelets are tested and scaled, signal to noise ratio for each offset or angle stack is also analysed. Performing the pre-stack simultaneous inversion at first will provide a quick look at the results above the inversion resolution ($\lambda/8$). Through the deterministic inversion process, we can give the final decision about the angle or offset stack scheme, wavelets scaling, signal to noise ratio. The facies-fluid probability analysis provides an overview of the proportions of each layer of the whole area.

For geostatistical inversion, the studied lithology is complex, in order to reduce the uncertainty, we combine I sand and II sand into one main lithotype, and combine the coal into the shale. Then apply geostatistical inversion to create 10 realizations and compute the mean P-Impedance, Vp/Vs ratio, density and lithology's probability volume. Figure 2 shows the comparison of Vp/Vs ratio section for deterministic and geostatistical inversions, (a) is the deterministic inversion result, (b) is geostatistical inversion without well constrained, (c) is the geostatistical inversion with well constrained, we can see that even without well constrained, the geostatistical inversion results are predicting wells data, and shows more information than the deterministic inversion .

Co-simulation of porosity was then performed by building the statistical relationship of P-impedance and porosity and to generate porosity volumes from each lithotype and P-impedance realization. Figure 3 shows sections of the effective reservoir probability without well constrained (a), with well constrained (b) and the mean porosity distribution generated from lithotype and P-impedance realizations with well constrained (c). We can see that geostatistical inversion can predict thin effective reservoir very well. Then the effective sand and the porosity distribution interpretation can be used to identify the sweet spots.

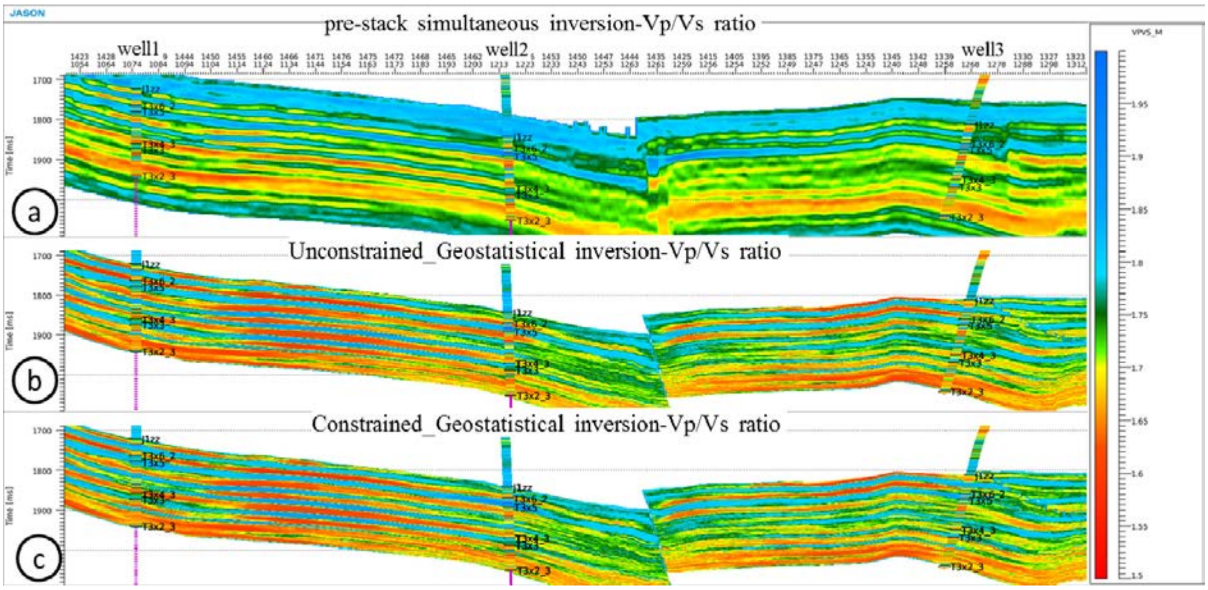

***Figure 2** (a) Vp/Vs ratio from pre-stack simultaneous inversion (b)Vp/Vs ratio from unconstrained Geotatistical inversion (c) Vp/Vs ratio from constrained Geostatistical inversion.*

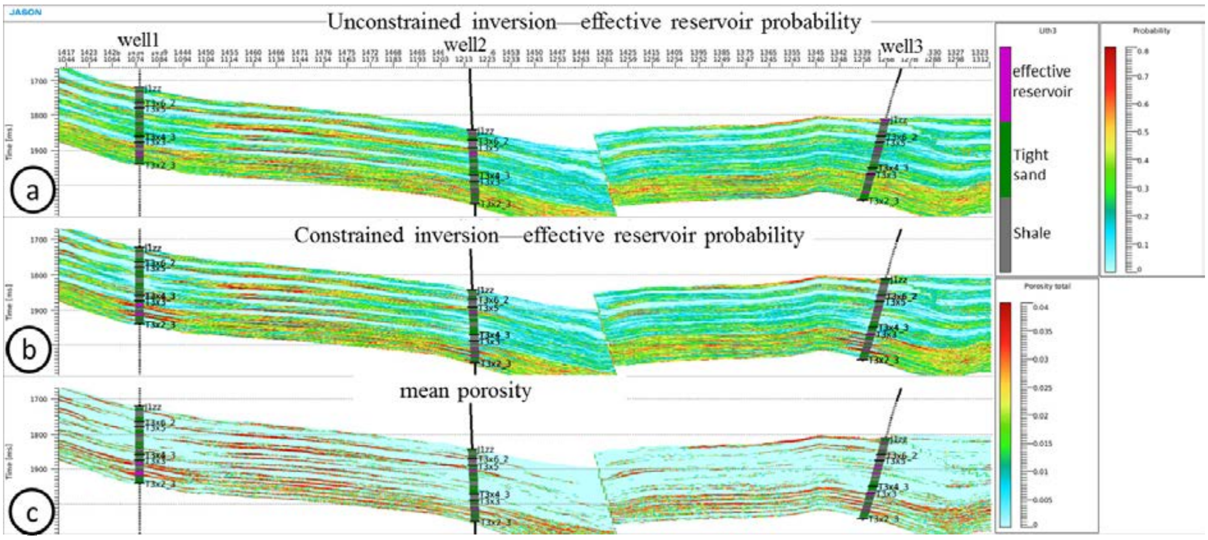

***Figure 3** (a) unconstrained inversion-effective reservoir probability cube (b) constrained inversion-effective reservoir probability cube (c) mean porosity.*

Figure 4 shows a comparison between the effective reservoir probability section through a new drilled well. The log is the low pass filtered effective porosity, filled for values above 2.5%, the red point is pointing the location of gas production. We can see that the geostatistical inversion has predicted the porosity with a high degree of confidence.

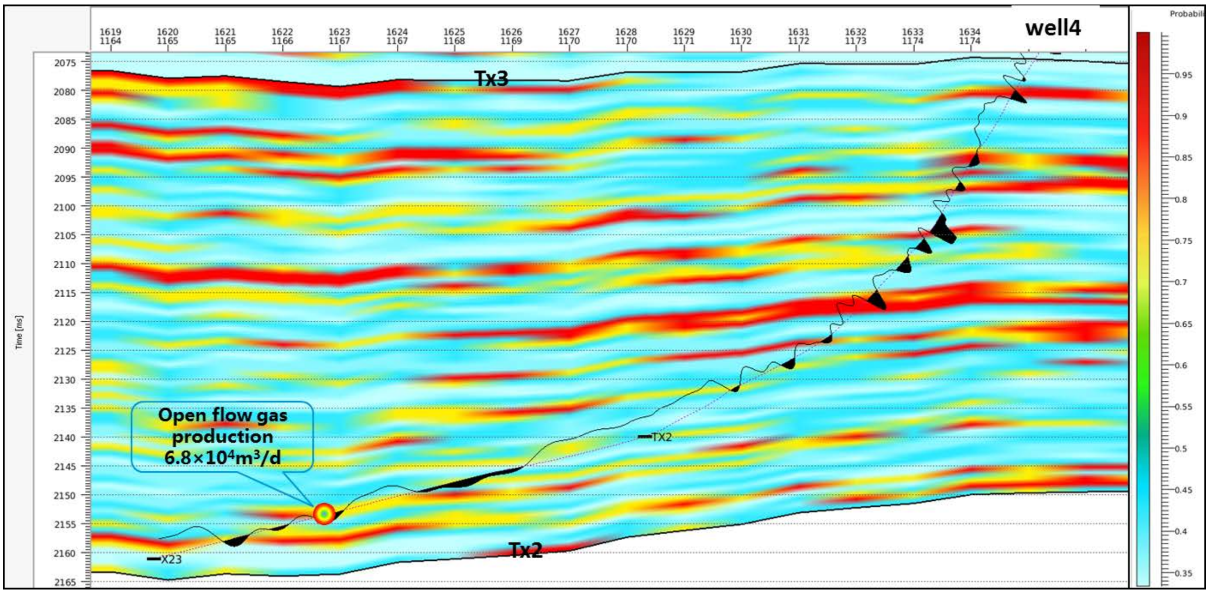

Figure 4 *effective reservoir probability section through new drilled well.*

Conclusions

Geostatistical inversion can get the effective reservoir and porosity distribution in Xujiahe formation for this gas field despite the limited vertical resolution of the seismic. New well data shows the validity of this technology, maximum solve the problem of the low porosity, low permeability and thin reservoir. These results show that seismic data can assist in choosing the optimum drilling location even if vertical resolution is limited.

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