



Application of Seismic Motion Simulation Method in Reservoir Prediction of Complex Clasolite

Chun-lin Xie¹(✉), Jing Sun², Qing Liang¹, Jie Wu¹, Wei-wei Liu¹,
and Xiaoyang Wang³

¹ Exploration and Development Research Institute of Daqing Oilfield Company Ltd., Daqing, China

xiecl@petrochina.com.cn

² Daqing Research Institute of BGP, Daqing, China

³ The Sixth Oil Production Plant of Daqing Oilfield Company Ltd., Daqing, China

Abstract. Geologic conditions of the second member of Xujiahe Formation in Hechuan area, Sichuan Basin, are complex. Different from the conventional clastic gas reservoir seal assemblage, the cap rock in this area is not mudstone but impermeable sandstone. Geologic requirements are quantitative prediction of sandstone, favorable reservoir (permeable sandstone) and net pay (gas-bearing sandstone). The following technical procedures are selected after a few tests in this paper: (1) Based on the petrophysical analysis, Gamma Ray curve is used to distinguish sandstone from mudstone; Porosity curve is applied to predict permeable sandstone; Resistivity and porosity curve are combined to predict net pay in the case that the elastic parameters cannot distinguish the gas layer from water layer. (2) Calculate Gamma Ray volume, porosity volume and net pay volume respectively by means of Seismic Motion Simulation. (3) Extract the thickness maps in time domain, which are further converted into the sandstone thickness maps, favorable reservoir thickness maps and net pay thickness maps. The workflow has effectively solved the reservoir prediction problems met in the second member of Xujiahe Formation, and has provided effective technical support for well deployment.

Keywords: Hechuan area · The second member of Xujiahe Formation · Petrophysical analysis · Seismic Motion Simulation

1 Introduction

Generally, the clastic sandstone and mudstone assemblage takes sandstone as the reservoir and overlying shale as the cap. When apparent impedance difference between sandstone and mudstone happens, strong seismic reflection forms. For conventional sandstone and mudstone assemblage, the net pay is the sandstone removing interlayers. Consequently, the spacial distribution patterns are similar for sandstone and net pay. The difficulty of prediction is mainly the identification of thin-beds. In recent years, both the methods of Seismic Motion Inversion (SMI) and Seismic Motion Simulation

(SMS) have performed well in predicting spatial distribution of the conventional clastic assemblage [1–10].

Although sedimentary facies of the second member of Xujiahe Formation (X_2), Sichuan Basin, are mainly delta front underwater distributary channel and mouth bar, merely the sandstone with relatively better physical property bears gas or water. Reservoir thicknesses vary abruptly from 1 m to 13 m. Since there is no obvious change between sandstone and mudstone measured from either Slowness or Density log curves, seismic reflection characteristic is not obvious. In such complex geologic condition, predictions of sandstone, favorable reservoir (i.e. permeable sandstone), and net pay (i.e. gas-bearing sandstone) are challenging. Aiming at reservoir prediction methods of X_2 , scholars have done a lot of hard work and have made some achievements. Both Chen X [11] and Zhang H [12] have predicted favorable reservoir by seismic facies, and Wang C [13] has predicted net pay by means of reservoir replacement and synthetic modeling. However, all the achievements are based on low resolution and qualitative predictions. In this paper, SMS method is applied and quantitative results with high resolution are obtained.

The biggest difference between SMI and traditional statistical inversion is the selection of statistical samples. The traditional method is based on the variation function in spatial domain, which can only roughly express the degree of spatial variation, and cannot reflect the characteristics of facies change. SMI, using the principle of sedimentology, makes full use of the lateral changes of seismic waveform to reflect the spatial variation of sedimentary facies, then analyzes the characteristics of high frequency components which reflect the lithology combination in vertical direction. Consequently, SMI is a seismic facies controlled inversion and is a real high frequency simulation method, and can make the inversion results from completely random to determined step by step.

SMS shares the same principle with SMI. When elastic parameters are not capable of predicting the interested volumes, such as porosity, permeability, SMS might be applied.

According to the procedure of SMS, the following steps are taken. Firstly, log curves which are respectively sensitive to lithology, physical property and gas layers are selected through petrophysical analysis; Secondly, SMS are carried out by applying appropriate inversion parameters and selected log curves; Thirdly, thicknesses of sandstone, favorable reservoir and net pay are extracted from different submembers.

2 Seismic Geologic Condition

As shown in Fig. 1, The formation thickness of the X_2 in Hechuan area, Sichuan Basin, ranges from 76 m to 139 m. It is divided into three submembers, namely X_2^1 , X_2^2 , and X_2^3 . The formation mainly develops delta front subfacies, of which the microfacies are underwater distributary channel, mouth bar, interdistributary area and distal bar. The physical property at the submember X_2^1 and X_2^2 is better than that at X_2^3 . The porosity mainly distributes 4%–9% with an average of 6.71%. The permeability varies from 0.01 mD to 1 mD with an average of 0.359 mD. Thick sandstone, amid which

distributes gas layers, is the main lithology. Logging curves show that both Slowness (DT) and Density (RHOB) curves do not change significantly at the lithologic boundary. However, they change at the layers, in which the Slowness curve changes from 61 $\mu\text{s}/\text{ft}$ to 65 $\mu\text{s}/\text{ft}$ and the Density curve changes from 2.58 g/cm^3 to 2.48 g/cm^3 .

Figure 2, the synthetic seismogram of well W125, shows that the top surface of gas layers correspond to negative reflection coefficients. Top surface of the first layer locates at the trough, of the second layer locates at Zero (-/+), of the third layer locates at Zero (+/-), of the fourth layer locates at the trough, and of the fifth layer is at the lower part of the peak. Therefore, seismic reflection characteristics of gas layer are very complex, and it is difficult to predict sandstone and favorable reservoir using seismic attributes. Seismic inversion or simulation is better way to predict the distribution of sandstone and reservoir.

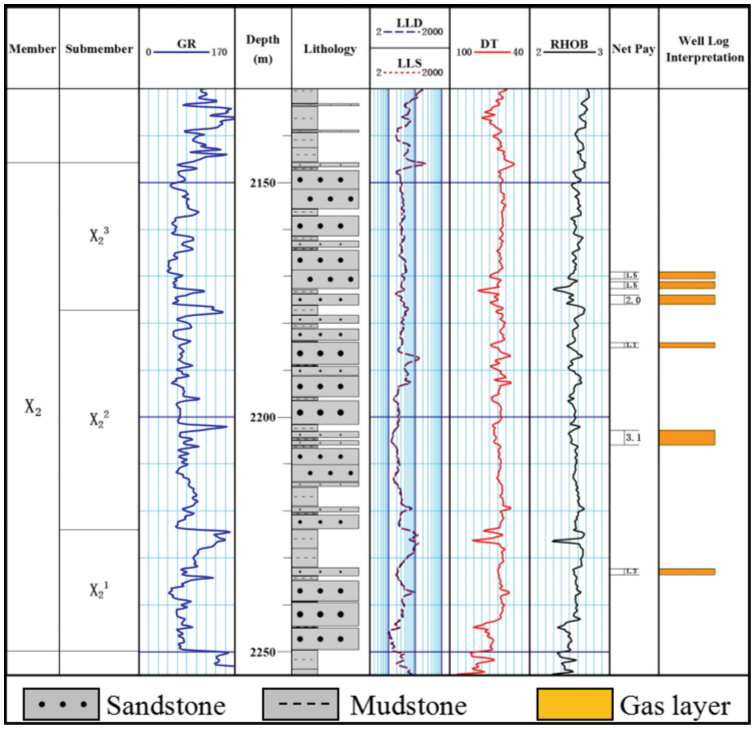


Fig. 1. Composite columnar section of well W125

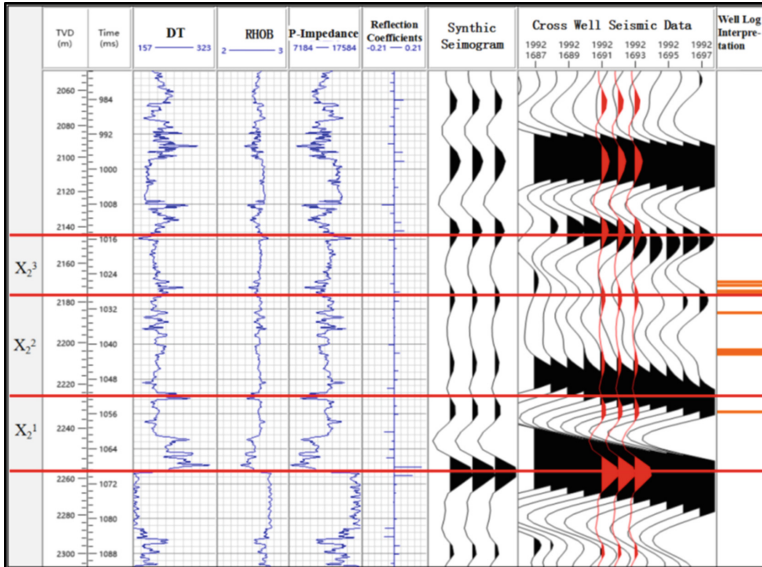


Fig. 2. Synthetic seismogram of well W125

3 Petrophysical Analysis

Petrophysical analysis is the basis of seismic inversion. Through petrophysical analysis, sensitive parameters of lithology, favorable reservoir and net pay are optimized. These parameters are applied in the process of SMS to simulate the corresponding volumes.

3.1 Prediction of Sandstone

Figure 3 shows the crossplot of Gamma Ray (GR) and ratio of P-wave to S-wave velocity (V_p/V_s). The black dots are mudstone samples, and dots of other colors represent sandstone samples. GR values greater than 90 API indicate mudstone while those less than 90 API represent sandstone.

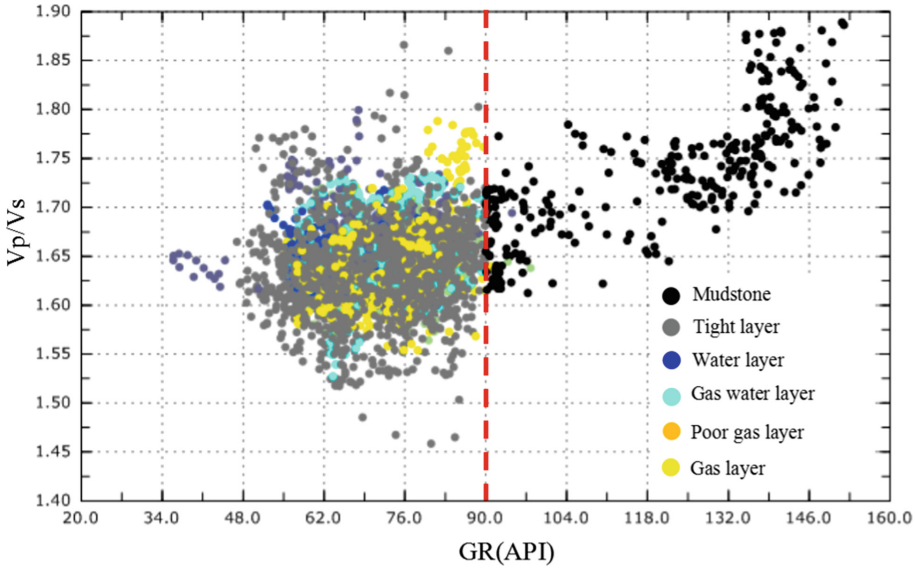


Fig. 3. Crossplot of Gamma Ray and Vp/Vs

3.2 Prediction of Favorable Reservoir

All the single logging curves cannot distinguish favorable reservoir from tight sandstone, whereas porosity is the most effective parameter to separate permeable sandstone from tight sandstone. Referring to LI Q’s logging identification method for low-resistivity gas layer in this area [14], the Multi-Cloud method is applied to calculate the effective porosity. Calculation formula is the following:

$$\varphi = 0.388313 \times DT + 0.384143 \times NPFI - 11.9411 \times V_{cl} - 19.8$$

Where φ stands for effective porosity, DT is value of Slowness logging curve, NPFI is value of Neutron logging curve, and V_{cl} is volume of clay which can be calculated by GR logging curve. The formula can also be used to calculate an effective porosity curve which identifies the permeable sandstone.

3.3 Identification of Gas Layer

Net pay thickness of gas layer is a main parameter for natural gas reserves submission. Figure 3 shows that Vp/Vs parameter neither distinguish between tight sandstone and permeable sandstone, nor between gas layer and water layer. Generally, Vp/Vs and Poisson’s ratio are sensitive parameters to identify gas layer [15–20]. However, in X₂ in this area, Vp/Vs, Poisson’s ratio as well as other elastic parameters cannot distinguish gas layer from water layer. Therefore gas layer identification methods have to be explored from other logging curves.

Parameters sensitive to gas layer in this formation are the Deep Lateral Resistivity curve and the Deep Induction Resistivity curve. Resistivity features of the X_2^3 and $X_2^1 + X_2^2$ submembers are obviously different. Gas layer of the X_2^3 is characterized by high resistivity, while that in $X_2^1 + X_2^2$ shows low resistivity. Consequently, two crossplots of porosity and resistivity are built to identify net pay in X_2^3 and $X_2^1 + X_2^2$. For instance, the lower limit values of porosity and resistivity are 6.4% and 8 $\Omega\cdot\text{m}$ respectively.

4 Seismic Motion Simulation

Based on the results of petrophysical analysis, GR curve simulation is used to predict sandstone, porosity simulation is used to predict favorable reservoir, and net pay simulation is used to predict gas reservoir.

4.1 Sandstone Prediction

The distribution of sandstone is quantitatively predicted by GR curve simulation. There are three main parameters in the process: (1) Valid sample value. It is the number of valid samples used to estimate the inversion results. A bigger valid sample results in a more spatially continuous inversion result. Due to the poor continuity of seismic events and the large number of wells involved in simulation, 6 is the best value in this area. (2) Best cut-off frequency value. If a more certain inversion result is preferred, the parameter should not be set too high. On the contrary, if a higher resolution result is needed and a more random result can be accepted, a higher cut-off frequency value can be set. Given the net pay thickness less than 13 m, 200 Hz of high-pass frequency and 250 Hz of high-cut frequency are chosen. (3) Smoothing radius value. It is another important parameter in controlling the variation of spacial distribution of reservoir. The larger the smoothing radius is, the better continuity of result predicted by the inversion is. Due to the poor continuity of seismic events, 6 is selected.

Figure 4 is a zigzag profile of GR simulation volume from well W1-3 to well W23-x2. It shows that the inversion result has a good relationship with the sandstone and mudstone displaying on wells and that the major lithology filling in this area is sandstone and mudstone merely distributes as the interlayers.

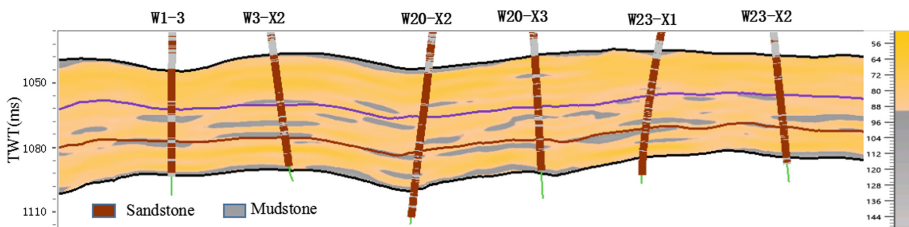


Fig. 4. A zigzag profile of GR simulation volume from well W1-3 to well W23-x2

4.2 Favorable Reservoir Prediction

The calculated effective porosity curve is used to simulate effective porosity volume and the parameters are the same as those of GR simulation. Figure 5 is a simulation zigzag profile of effective porosity volume. It has a good correlation with reservoirs calibrated on wells. The result shows that X_2^1 owns the best porosity, and the X_2^2 owns the middle porosity, while the X_2^3 owns the poorest porosity.

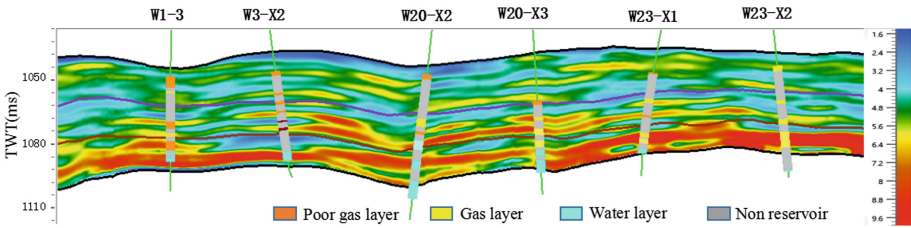


Fig. 5. A zigzag profile of effective porosity simulation volume from well W1-3 to well W23-x2

4.3 Net Pay Prediction

According to the petrophysical analysis mentioned above, the net pay curve is formed to simulate the spacial distribution of net pay. The simulation parameters are the same as above. Figure 6 is a zigzag profile of net pay simulation volume from well W1-3 to well W23-x2. It has a good correlation with net pay calibrated on wells. Compared with the favorable prediction volume in Fig. 5, the water layers have been removed from Fig. 6.

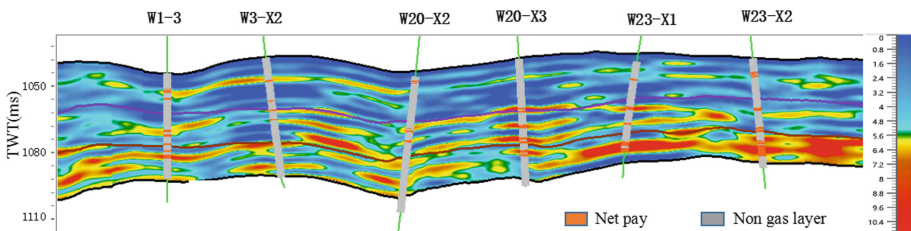


Fig. 6. A zigzag profile of net pay simulation volume from well W1-3 to well W23-x2

Based on the SMS volumes mentioned above, the thickness of sandstone, favorable reservoir and net pay are mapped. As shown in Fig. 7, the overall morphologies of the three plan maps are similar. The thickness of sandstone (a) is 20 m–60 m, the thickness of favorable reservoir (b) is 0 m–16 m, and the distribution range of net pay thickness (c) is 0 m–12 m.

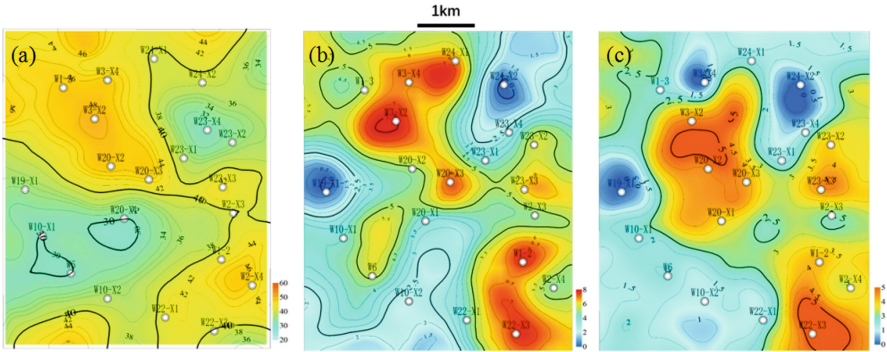


Fig. 7. Thickness maps of (a) sandstone, (b) favorable reservoir and (c) net pay in X_2^3 .

Based on the plane maps of sandstone, favorable reservoir and net pay, the distribution of gas reservoir is basically revealed. These maps provide a basis for well deployment in the area.

5 Conclusions

Through the Seismic Motion Simulation of the X_2 in Hechuan area, conclusions are made as follows:

- (1) SMS is based on Petrophysical analysis and well logging interpretations, which play a decisive role in the accuracy of simulation results. The simulation volumes are mainly based on porosity curve and net pay curve, which overcomes the difficulty of using either original well logging curves or elastic parameters in the past. Applying these parameters is a change of inversion thinking.
- (2) For the abruptly varied reservoir, low seismic resolution at X_2 , SMS method is effective in predicting sandstone, favorable reservoir and net pay thickness, which are important geologic maps for well deployment and reserve submission.
- (3) The quantitative prediction workflow gives a good reference to the prediction of complex clastic reservoir in other areas.

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