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Prediction Technology for Top Gas Reservoir of Oil and Gas Reservoir of Three-Dimensional Seismic Pre-Stack Parameters: Application in Jinzhou South Oil and Gas Field in Bohai Sea

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Abstract

It is the key of using the oil layer efficiently to avoid the top gas reservoir of the oil and gas reservoir in the development of the offshore oilfield. The oil reservoir in the second member of the Shahejie Formation of the Jinzhou South Oilfield in the Bohai Sea is a complex oil and gas reservoir of top gas, narrow oil ring and edge water. The oil and gas reservoir is longitudinally divided into multiple sets of fluid systems, and the gas-oil interfaces of different fault blocks are not consistent with large differences. The positions of the gas-oil interfaces and oil-water interfaces need to be determined precisely in the development and design of the horizontal wells on the drilling platforms, so as to prevent the premature gas channeling and water invasion of the production wells. Thus the identification of the top gas reservoir is particularly important. In this paper, we used seismic attribute analysis, pre-stack elastic parameter coordinate rotation method fluid detection and other technologies to identify the top gas reservoir of the oil and gas reservoir in the second member of the Shahejie Formation of the Jinzhou South Oilfield in the Bohai Sea, and obtained good application effects.

Key words: Oil and gas reservoir; Top gas reservoir; Three-dimensional seismic; Seismic attributes; Pre-stack elastic parameter coordinate rotation method; Fluid detection

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INTRODUCTION

The oil reservoir in the second member of the Shahejie Formation of the Jinzhou South Oilfield in the waters of the Bohai Sea is the complex oil and gas reservoir of top gas, narrow oil ring and edge water. The oil and gas reservoir is longitudinally divided into multiple sets of fluid systems, and the gas-oil interfaces of different fault blocks are not consistent with large differences. For the narrow oil ring oil reservoir type with top gas and edge water, the horizontal wells are mainly used for development. The positions of the gas-oil interfaces and oil-water interfaces need to be determined precisely in the development and design of the horizontal wells, so as to prevent the premature gas channeling and water invasion of the production wells. In addition, the depth of the horizontal section needs to be located in the 1/2 place between the gas-oil interfaces and the oil-water interfaces, so as to guarantee the long-term and stable yield of the production wells.

Due to the facts that the well spacing of the appraisal wells of the offshore oilfield is large and the well pattern of the development wells is sparse, it is difficult to implement the gas-oil interfaces of all the fault block oil and gas reservoirs. Therefore, in this paper, we carried out a study on the identification of the gas reservoir distribution range by using the three-dimensional seismic pre-stack parameters.

Aiming at the geological characteristics of the Jinzhou South Oilfield, first, we carried out the seismic processing research based on the pre-stack trace gathers for the seismic data to improve the quality of the basic data; second, we conducted physical experiments on the sensitive seismic petrophysical parameters of the gas reservoir as well as the petrophysical parameter and fluid substitution forward modeling studies, and determined the response characteristics of the gas reservoir on the pre-stack trace gathers and the post-stack data on this basis; finally, we used the post-stack seismic amplitude attributes

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as well as the fluid prediction technology based on the pre-stack elastic parameter coordinate rotation method to determine the distribution range of the gas reservoir.

1. PRE-STACK TRACE GATHER AVO BACKGROUND TREND CORRECTION TECHNOLOGY BASED ON FLUID DETECTION

Castagna (1997) et al. pointed out that, under the conditions of good compaction, the normal reflection coefficient P and gradient G of most water-saturated sandstone and mudstone interfaces were distributed within the background lines within a narrow range. This phenomenon is known as the AVO background trend line.

The existence of the AVO background trend line is also found through the statistics of the forward data of the model. When the PG distribution plane intersection characteristics extracted from the seismic trace gathers in the water-saturated position are inconsistent with the forward model, generally it is the interference caused by the factors of uncertainty in the seismic trace gathers, and this situation needs to be corrected.

The theoretical curve is obtained through the calculation of the AVO model. Taking the horizon data of the wells as the parameter for the AVO model, the corresponding theoretical amplitude curve can be calculated through the offset curve of the seismic traces near the wells.

The simulation application of the AVO simplifies the Zeoppritz equation, and the formula is as follows:

$$RC(\theta) \approx \frac{1}{2}\left(\frac{\Delta\alpha}{\alpha}+\frac{\Delta\rho}{\rho}\right)+\left[\frac{1}{2}\frac{\Delta\alpha}{\alpha}-2\left(\frac{\beta}{\alpha}\right)^2\left(\frac{2\Delta\beta}{\beta}+\frac{\Delta\rho}{\rho}\right)\right]\sin^2\theta+\frac{1}{2}\frac{\Delta\alpha}{\alpha}\left(\sin^2\theta\tan^2\theta\right)$$

(In the formula, θ is the reflection angle, β is the average value for the velocities of the upper and lower shear waves, α is the average value for the velocities of the upper and lower longitudinal waves, ρ is the average value for the upper and lower densities, $\Delta\beta$ is the variable quantity for the velocities of the upper and lower shear waves, $\Delta\alpha$ is the variable quantity for the velocities of the upper and lower longitudinal waves, and $\Delta\rho$ is the variable quantity for the upper and lower densities), the theoretical curve of the amplitude can be obtained through the above formula[1].

We conducted the statistics for the amplitude of the seismic data according to the actual angle gather, used the least square method to fit and calculate the relation of change for the actual amplitude with the reflection angle, compared the forward amplitude change relation of the model with the amplitude change relation of the actual data, obtained the AVO background correction proportion curve for the actual data, and applied it to the overall data of the section to be researched.

During the correction, the order of magnitude between the theoretical amplitude curve and the actual amplitude curve may be different, and the theoretical amplitude curve was balanced to the order of magnitude, which is same as that of actual amplitude curve through equilibrium. The fitting curve of the actual amplitude curve was obtained through the fitting of the actual amplitude curve, and the calculation was conducted by using the following formula: Actual amplitude value/correction result amplitude value = actual amplitude fitting value/theoretical value; thereby obtaining the correction proportion.

After the correction processing of the pre-stack trace gather AVO background trend, it can be seen that, compared with the response characteristics before the processing, the AVO response characteristics of the gas reservoir section were enhanced significantly (Figure 1), and they are better consistent with the forward modeling results of AVO.

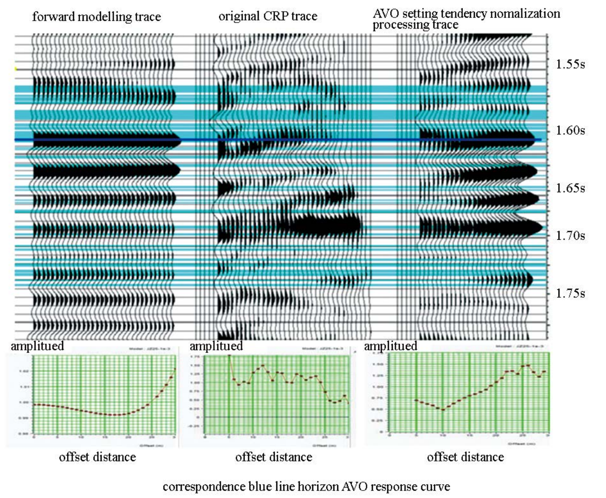

Figure 1
Comparison of Correction Processing Results of the AVO Background Trend Based on Pre-Stack Traces Gathered (The Light Blue Shading Is the Interpretation Reservoir)

2. SENSITIVITY ANALYSES OF PETROPHYSICAL PARAMETERS OF GAS RESERVOIR

2.1 Physical Experiment Analysis of Sensitivity of Petrophysical Parameters of Gas Reservoir

In order to obtain more accurate petrophysical sensitivity parameters of fluid, we selected two rock core samples in the area, and carried out the physical experiments on the sensitivity of the seismic petrophysical parameters under conditions of gas and water saturation.

Through experimental analysis, under the gas-and-water-saturated situation, compared with other seismic petrophysical parameters, the density, bulk modulus, shear modulus and other constants all had high sensitivity to the

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fluids (Figure 2). However, in the parameters which affect the seismic impedance (namely density, longitudinal wave velocity and shear wave velocity), the sensitivity of the density to the fluid was strongest, and compared with density, the sensitivity of the gas-saturated sandstone and water-saturated sandstone were reduced significantly, also having a great impact on the impedance of the longitudinal waves. The longitudinal wave impedance is shown as obvious low impedance characteristics in the gas-contained sandstone section[2].

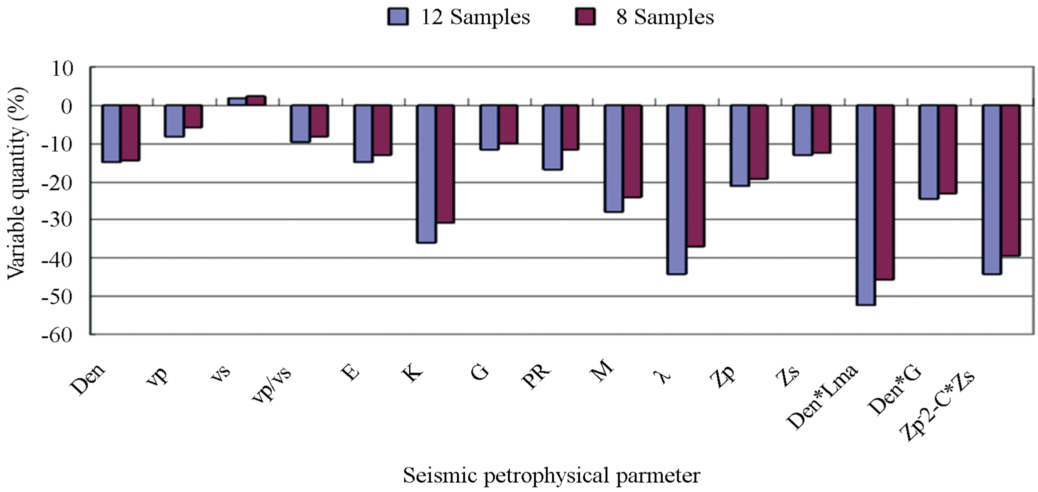

Figure 2
Sensitivity Analysis of Gas-and-Water-Saturated Seismic Petrophysical Parameters

2.2 Study on Petrophysical Characteristics of Gas Reservoir

The results of the petrophysical intersection analysis show that the gas reservoir is characterized by low gamma, low density, low longitudinal wave velocity, low longitudinal wave impedance, low velocity ratio of longitudinal wave and shear wave, low Poisson's ratio, low Lame constant, low flow impedance and high resistivity (namely "eight low and one high") (Figure 3).

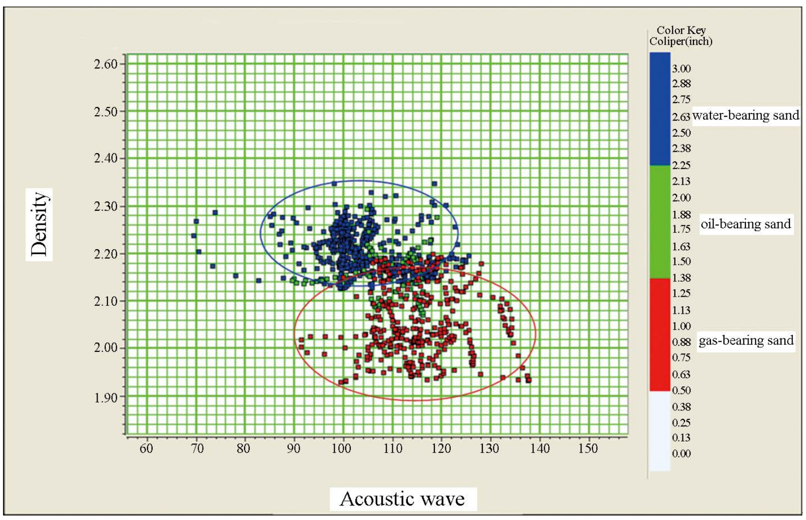

Figure 3
Crossplot of Acoustic Wave and Density of Sandstone Containing Different Fluids

2.3 Seismic Forward Modeling Study on Gas Reservoir Fluid Substitution

When the density of the gas-contained sandstone was reduced significantly, the gas-contained sandstone will certainly have a strong influence on the seismic reflection. In order to more accurately determine the characteristics of the gas-contained seismic response as well as the AVO characteristics and type, we conducted the seismic forward modeling study on gas reservoir fluid substitution.

We established the AVO forward model according to the oilfield reservoirs and fluid parameters, and carried out the forward modeling study on AVO response characteristics. As shown in Figure 4, the AVO response characteristics of gas-contained sandstone are Class II AVO response characteristics.

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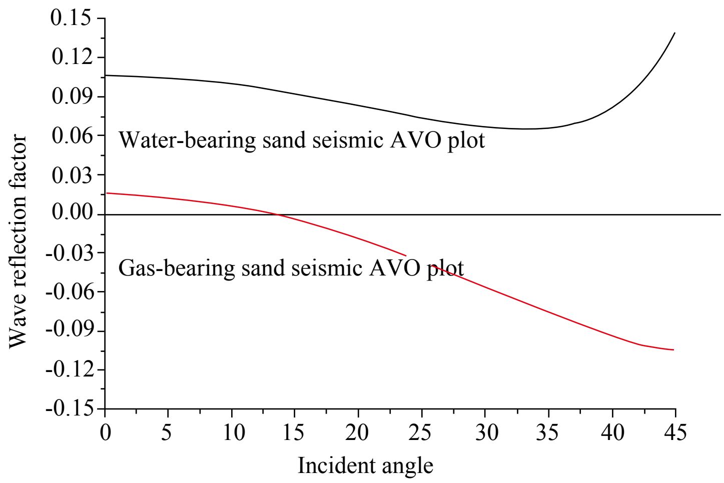

Figure 4
AVO Response Characteristics of Gas Reservoir

We selected the gas-contained wells of the oilfield to conduct the fluid substitution for the gas reservoir section, and replaced the sandstone containing gas with the sandstone containing oil and water, so as to carry out the forward modeling of the AVO. The simulation results show that, after the gas reservoir is replaced by the water layer, the value of the density increases significantly (Figure 5), but the acoustic waves change little. Due to the fact that the significant increase of the density causes the significant increase of the impedance value of the longitudinal wave, the differences between the sandstone impedance and the impedance of the overlying mudstone increase significantly. Therefore, the amplitude of the top surface of the water-bearing reservoir is enhanced significantly, showing characteristics of strong amplitude reflection.

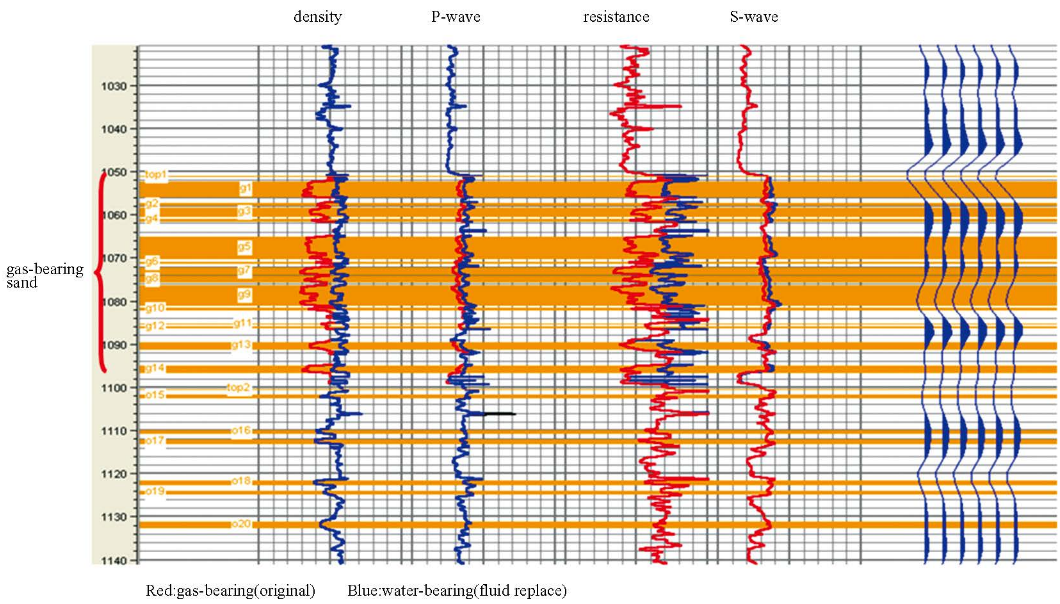

Figure 5
Forward Modeling Study on Fluid Substitution of Sandstone Containing Gas

3. STUDY ON SEISMIC PREDICTION TECHNOLOGY OF GAS RESERVOIR

3.1 Post-Stack Seismic Response Characteristics of Gas Reservoir and Prediction Technology of Gas Reservoir Distribution Range

The reservoir development section of the Jinzhou South Oil and Gas Field in the Bohai Sea is the second member of the Shahejie Formation. The upper and lower surrounding rocks are respectively the stable mudstone depositions of the Dongying Formation and third member of Shahejie Formation. The differences in the density and acoustic wave curves of the mudstone sections of the upper and lower surrounding rocks are small, the wave impedance differences are very small, the whole presents the weak characteristics of amplitude reflection, and the

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structural high parts are manifested as dim spots (Figure 6). After the reservoir in the structural low part contains oil, the density of the oil-bearing sandstone is not reduced significantly; the impedance differences of the sand and mud interface of the reservoir top are obvious; thereby exhibiting strong characteristics of amplitude response[3]. The obvious amplitude variations are shown in the position of the gas-oil interface, and thus the position of the gas-oil interface can be determined according to the variations of the amplitude[4].

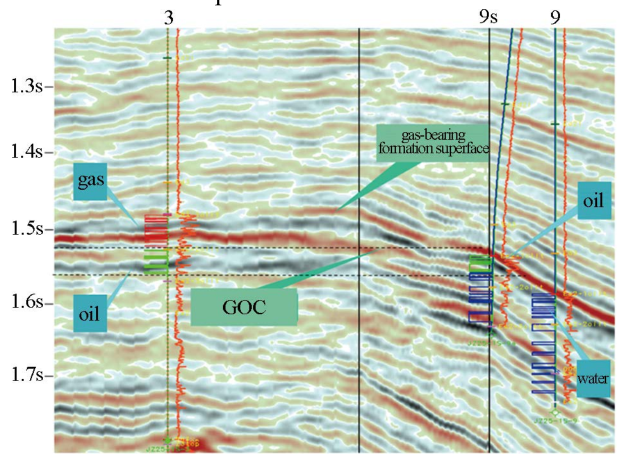

Figure 6
Response Characteristics of Gas Reservoir on Post-Stack Seismic Profile

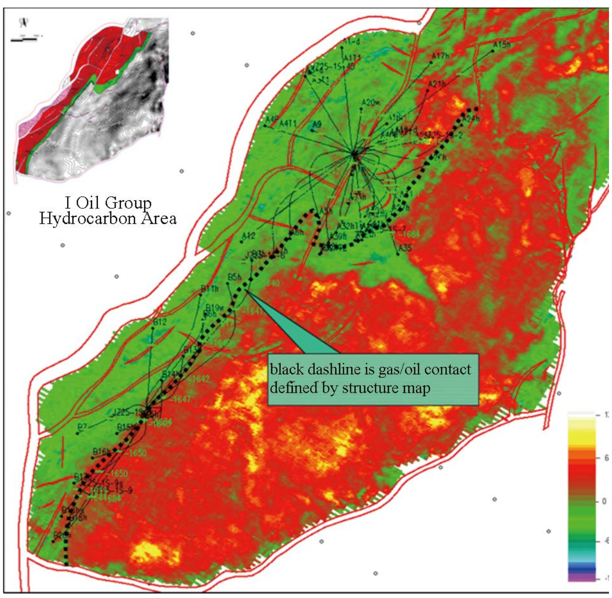

Figure 7
Gas Reservoir Distribution Range Predicted by Seismic Amplitude Attributes of Gas Reservoir Top Surface

Through the obvious characteristics of seismic amplitude variation existing in the position of the gas-oil interface, the range of the oil and gas reservior containing gas can be clearly delineated on the seismic amplitude attribute figure (Figure 7), and the approximate positions of the gas-oil interfaces can be determined[5], being nearly consistent with the positions of the oil-gas interfaces determined and confirmed by the drilling of the late development wells. This also verifies the influence of the gas reservoir on the seismic amplitude, and guides optimized deployment for the positions of gas recovery wells and oil production wells.

3.2 Pre-Stack Elastic Parameter Coordinate Rotation Method Gas Reservoir Detection Technology

During the intersection analyses of the fluid sensitivities of the petrophysical parameters of the oilfield, it was found that the sensitivities of the conventional petrophysical elastic parameters for the distinguishing of fluids are not good.

However, during the intersection analyses of the impedances of the longitudinal and shear waves (Figure 8), it was found that, the distribution regularities of the impedances of the longitudinal and shear waves were good, and overall they present parallel distribution and have certain intersection angles with the coordinate axis. If the coordinate rotation method is used to rotate the coordinate axis to a certain angle, the impedances of the longitudinal and shear waves can better distinguish the reservoirs and fluids. According to the rotation formula of the coordinate axis (1),

$$\begin{aligned} x' &= AI\cos(\phi) + SI\sin(\phi) \\ y' &= SI\cos(\phi) - AI\sin(\phi) \end{aligned} \tag{1}$$

The above coordinate rotation method was used to conduct the rotation of the coordinate axis, and the abscissa of the coordinate axis after the rotation can be represented as follows: $EEI(\phi) = AI\cos(\phi) + SI\sin(\phi)$ (where, AI is longitudinal wave impedance, SI is shear wave impedance, and ϕ is the angle).

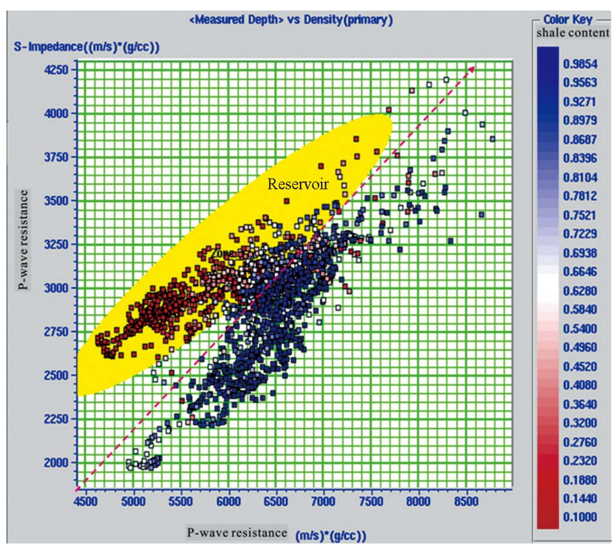

Figure 8
Intersection Analysis of Impedances of Longitudinal and Shear Waves

Further studies show that, when the angle ϕ in the abscissa $EEI(\phi) = AI\cos(\phi) + SI\sin(\phi)$ is constantly changed, it always has a high correlation with the fluid sensitivity parameters (including water saturation, Poisson's ratio, velocity ratio of longitudinal and shear waves, bulk modulus and Lame constant)[5]; In addition, during the constant rotation of the angle ϕ, the angle which has the best correlation with the fluid sensitivity parameters can always be found, after which the parameter which reflects the new attribute of the fluid can be calculated. We can define the attribute as the fluid impedance attribute *EEI (ϕ)*, and the new attribute can reflect the fluid nature.

In order to achieve the accurate detection of the fluid (gas reservoir), we selected the water saturation curve to conduct the correlation analysis. As shown in Figure 9, we used the fluid impedance attribute, namely $EEI(\phi) = AI\cos(\phi) + SI\sin(\phi)$ and the water saturation curves of all the wells to carry out the correlation analysis. When the angle is *305°*, the relevance is highest. In this way, the fluid impedance attribute which is correlated with the fluid can be calculated, that is to say, $EEI(305°) = AI\cos(305^0) + SI\sin(305^0)$, and accordingly, the fluid detection results can be obtained.

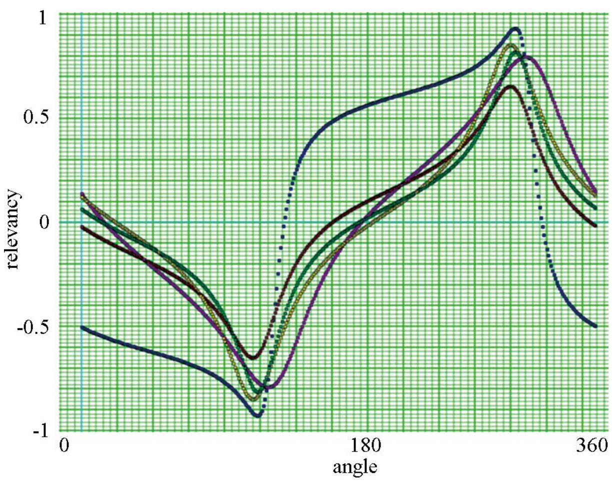

Figure 9
Correlation Analyses of Fluid Impedance Attributes and Water Saturation (the Lines of Different Colors Represent Different Well Types)

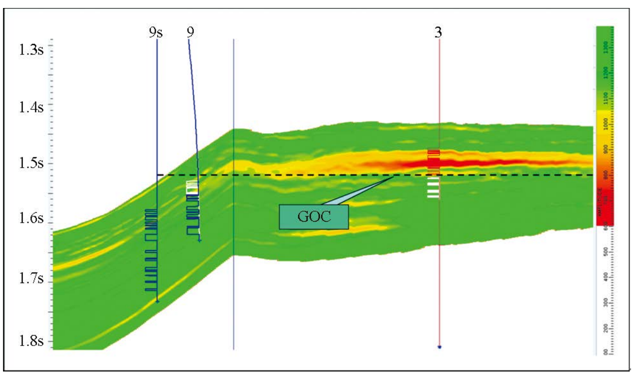

Figure 10
Contrast of Fluid Impedance Gas Reservoir Prediction Results and Actual Drilling

The fluid impedance prediction data volume was obtained by using the pre-stack elastic parameter inversion results and fluid impedance calculation formula, as shown in Figure 10. The fluid impedance gas reservoir prediction results are more consistent with the actual drilling.

4. APPLICATION AND EFFECT ANALYSIS

In order to reduce the multiplicity of the gas reservoir prediction, we used two kinds of data and methods (namely pre-stack and post-stack) to carry out the comparison of the seismic prediction results, and the two prediction results produced good consistency, increasing the reliability of the predictions of the gas reservoir distribution range and gas-oil interfaces.

We conducted the optimized deployment of the well locations according to the data volume of gas reservoir prediction, determined the design depth of the horizontal wells of the oil production, and designed 18 horizontal development wells. The accurate gas-oil interface depth prediction prevents the premature gas channeling or water invasion of the production wells, and guarantees a high and stable yield for the production wells.

Through the implementation of the drilling for the gas-oil interfaces, the error of the gas-oil interface prediction and actual drilling results of each fault block is within 8 meters, better solving the problems of the oilfield, namely complex gas-oil interface and large implementation difficulty.

CONCLUSION

Limited to the special production conditions at sea and the complex oil and gas reservoir types in the south area of Jinzhou, based on the pre-stack trace gather AVO background trend correction processing, the response characteristics of the gas reservoir in the reservoir section can be determined in combination with the physical experiment on the seismic sensitivity of fluid, petrophysical parameter intersection analysis, and forward modeling for fluid substitution. On this basis, the range of the top gas reservoir of the oil and gas reservoir can be identified accurately by conducting the post-stack amplitude attribute gas reservoir distribution range prediction and pre-stack elastic parameter coordinate rotation method gas reservoir detection. The drilling of the development wells confirms that the prediction results have good consistency. Therefore, the prediction technology of top gas reservoir of oil and gas reservoir of three-dimensional seismic pre-stack parameters in this paper has certain application prospects in the description aspect of solving the distribution of the oil and gas reservoir fluids; provides an effective method of prediction for solving the bottleneck which restricts the development of the gas and oil fields, namely the large difficulty

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of determining the offshore oil and gas reservoir fluid interfaces; and simultaneously provides the basis for the optimized deployment of the locations for the development wells of the oil and gas reservoirs and the realization of the effective development of the oil and gas reservoirs.

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