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Research on Identification Method of Argillaceous Interlayer in Compound Sand

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Abstract

For the compound sand body, the interlayer is an important factor affecting the adjustment of oil production structure and remaining oil distribution. According to the origin of argillaceous interlayer, the interlayer is divided into three types, including barriers between two single layers, intercalations between two single sands and intercalations in a single sand. In this study, the upper limit of physical properties of interlayer was obtained by analyzing the relationship between physical parameters and production index per-meter. The discriminant index and comprehensive discriminant chart of interlayer were obtained by grey correlation method, which realize the quantitative identification of different types of interlayer. The intercalations between two single sands in the target area are distributed almost in the whole area, which is one of the most important factors influencing the mining effect of compound sand, so the planar distribution is mainly aimed at it. Firstly, through cross-well comparison, we summarize three interlayer patterns, then establish their forward modeling, so as to obtain the vertical seismic characteristics of different patterns. Secondly, according to the thickness of intercalations between two single sands, we take the top of bottom sand as the baseline, extract the average amplitude attribute from the upper and lower 3 ms, then, according to the seismic section and planar characteristics of the well, the interlayer structures represented by different seismic section and planar characteristics are summarized. Finally, starting from the real drilling interlayer of the well, the planar spread of interlay can be obtained according to their variation trend and distribution.

Keywords

Compound Sand, Interlayer, Quantitative Identification, The Planar Distribution of Interlay

1. Introduction

For the compound sand body, the interlayer is an important factor affecting the adjustment of oil production structure and remaining oil distribution. The A Oilfield is located in the central Bohai sea area. The main production layer is Minghuazhen Formation (Nm), which belongs to the deposit of the meandering river. The porosity of the reservoir is 20% to 40% and the permeability is 200 - 5000 mD. At present, horizontal wells are used for oil production and directional wells for water injection, and horizontal wells are mainly deployed at the top of sand body. Because of the positive rhythm of meandering river reservoirs, there is a large difference in the amount of water absorbed between the upper and lower layers, resulting in insufficient energy in the horizontal wells above the layers and the accumulation of remaining oil at the bottom. Therefore, in order to solve the contradictions in the compound sand body, it is necessary to carry out a detailed study on the interlayer.

At present, domestic and foreign scholars mainly use logging for qualitative description in the study of interlayer, while quantitative characterization is less. In particular, due to the large well spacing and limited data in offshore oil fields, quantitative evaluation and characterization of interlayer are rarely studied [1] [2]. In this paper, taking A oilfield as an example, an innovative method of interlayer plane characterization based on the quantitative identification map of interlayer well and the integration of geology, logging and seismic is proposed, which solves the contradictions within the interlayer to a certain extent.

2. Identification Method of the Interlayer

The identification methods of interlayer are mainly based on core, logging, testing and production data. In this paper, the upper limit of physical properties, the types of interlayer, characteristics and quantitative identification of interlayer are mainly studied.

2.1. Upper Limit of Physical Properties

The interlayer is a non-permeable or low-permeable formation, and its physical properties are less than the lower limit of effective reservoir physical properties [3]. The production index per-meter is the production of one meter's formation under unit pressure difference, which can indirectly reflect the physical properties of the reservoir. Therefore, the upper limit of the physical properties for interlayer can be determined according to the relationship between the production index per-meter and the physical properties of the reservoir.

According to the core analysis and oil testing data of exploration wells, the physical properties of reservoirs have the following relationship with production index per-meter, porosity and permeability are positively correlated with it, when porosity is less than 25% or permeability is less than 200 mD, the production index per-meter is 0 and then the oil layer has no production capacity. The shale content is negatively correlated with it, when the shale content is greater than 13%, the oil layer has no production capacity. That is, the upper limit of physical properties of interlayer is that, porosity is 25%, permeability is 200 mD, and the lower limit of shale volume fraction is 13%.

2.2. Genetic Classification and Characteristics

Argillaceous interlayer is a lithologic or physical interlayer between sand bodies and inside sand bodies caused by hydrodynamic changes during deposition. The interlayer can be divided into three types according to its origin, including barriers between two single layers, intercalations between two single sands and intercalations in a single meander river bar.

Barriers between two single layers

The barriers between two single layers are composed of floodplain and its residual mudstone, which are extensively developed during flood season. The plane drilling rate is more than 65%, and the vertical thickness is greater than 5 m. The lithology of the barriers between two single layers is purplish red, grayish yellow or green mudstone, mixed with argillaceous siltstone, which is massive bedding and the structure of plant roots and wormholes can be seen. The gamma value is relatively high, which is a linear or dentate baseline, and the resistivity value is low. The average porosity is 12.8%, the average permeability is 25MD, and the argillaceous content is 65%.

Intercalations between two single sands

The intercalations between two single sands are composed of abandoned channel mudstones and residual flood plain. The plane drilling rate is relatively high and the average thickness is 2.5 m, which change from 1 to 4 m. The lithology of the intercalations between two single sands is mainly purplish red and grayish green mudstone or silty mudstone, which is the product of weak hydrodynamic force and insufficient material supply, showing parallel bedding. Gamma and resistivity are dentate, with obvious contrast with the logging values of surrounding rock. The average porosity is 19%, the average permeability is 95 MD, and the argillaceous content is 45%.

Intercalations in a single meander river bar

Intercalations in a single meander river bar are thin mudstone and argillaceous siltstone developed in river channel during dry season and flood break. This type of interlayer has a small distribution range and low planar traceability. The thickness is 0.5 - 2.0 m and the lithology is grey mudstone or argillaceous siltstone. The logging curve is greatly influenced by the surrounding rock, and its return degree is positively correlated with the interlayer thickness. The average porosity is 29%, the average permeability is 980 mD, and the argillaceous content is 24%.

2.3. Identification Method

Logging curve is a comprehensive response of lithology, surrounding rock, fluid and other factors, so it is difficult to accurately identify the type of interlayer by a single curve.

Starting from 15 exploration wells in A oilfield, this study calculated the correlation between the interlayer and gamma, resistivity, porosity, permeability, argillaceous content and thickness, the result show that gamma, resistivity and thickness are more sensitive to interlayer. Therefore, this study takes them as main parameters, uses gray correlation method to carry out dimensionless and difference processing, then calculates the correlation coefficient of each parameter, and finally completes the coefficient normalization processing to obtain the coefficient of each parameter. The discriminant index of interlayer is obtained by multiplying the coefficients with the corresponding parameters respectively and then summing them up.

$$I = 0.32GR + 0.39R + 0.29H \tag{1}$$

Note: Ire is the interlayer discrimination index; GR is gamma, API; R is resistivity, Ω·m; H is the interlayer thickness, m.

Since the interlayer discrimination index is influenced by surrounding rock, this study combines the discriminant index with the physical parameters to form a comprehensive discriminant chart to realize quantitative identification of the interlayer on the well. The discriminant index of barriers between two single layers is greater than 30, the argillaceous content is greater than 40%, and the porosity is less than 23%. The discriminant index of intercalations between two single sands is less than 30, argillaceous content is more than 30%, and porosity is less than 25%. The discriminant index of intercalations in a single sand is less than 35, argillaceous content is less than 30%, and porosity is greater than 25%.

The core of well B, a closed coring well in the later stage, was used to verify the above chart, and the coincidence rate reached 93%. However, using conventional logging data to identify interlayers may miss 40% of the intercalations in a single meander river bar. Therefore, the chart can be used to judge the type of interlayer in production wells.

3. Analysis of Interlayer Distribution

Through cross-well comparison, it is recognized that the barriers between two single layers are distributed in almost the whole area and have a large thickness, which play a role in blocking oil, gas and water [4]. The planar distribution of intercalations in a single sand is limited, and its distribution scope mainly depends on geological knowledge base. This study is mainly aimed at the intercalations between two single sands.

The intercalations between two single sands among main oil-producing layers in A Oilfield are developed in almost the whole area, but the thickness changes greatly. There are three different styles, including thick interlayer formed by weak cutting and stacking among sand bodies, thin interlayer formed by strong cutting, and multiple sets of interlayer formed by cutting and stacking of multi-stage sand bodies [5] [6]. This paper obtains the longitudinal and planar distribution of interlayer through the combination of forward modeling and actual well seismic data.

3.1. Forward Modeling and Seismic Profile Characteristics

For the above three different types of interlayers, forward modeling is established respectively, and the results are consistent with the seismic response of the interlayer drilled on the well. The thick interlayer is characterized by complex wave. As the thickness decreases, the amplitude of complex wave decreases and the profile can be identified and tracked. The thin interlayer is also characterized by complex waves, but its amplitude is weak and can be traced within a certain range on the section. The multiple sets of interlayer shows multiple sets of complex waves with weak amplitude (**Figure 1**).

The interlayer thickness on the well in the target area is from 0 to 4 m. On the basic of fine comparison of small layers in the whole region, taking the top of the bottom sand as the baseline and the 3 ms above and below the baseline as the time window, the average amplitude attribute is extracted. From the well point seismic profile, it can be seen that the top of the single sand is a wave trough, the amplitude within the time window is strong negative-negative amplitude, and the whole amplitude is strong.

The sand roof under the thick interlayer is located in the valley of complex wave and the amplitude is weakened affected by the upper reservoir. The amplitude is a relatively strong negative-negative amplitude superposition within the time window, and the overall amplitude is relatively strong. As the interlayer thickness decreases, the complex wave amplitude gradually weakens until there is no interlayer, and the waveform becomes peak to valley. According to the principle of equal thickness comparison of rivers, the waveform on the top of the bottom sand body is at 0 phase, the overall amplitude is weak because of the cancellation of positive and negative waves within the time window. Due to the complex wave, the amplitude of interlayer between sand bodies in multi-stage is weak. In short, the average amplitude can reflect the distribution of interlayers to a certain extent (**Figure 2**).

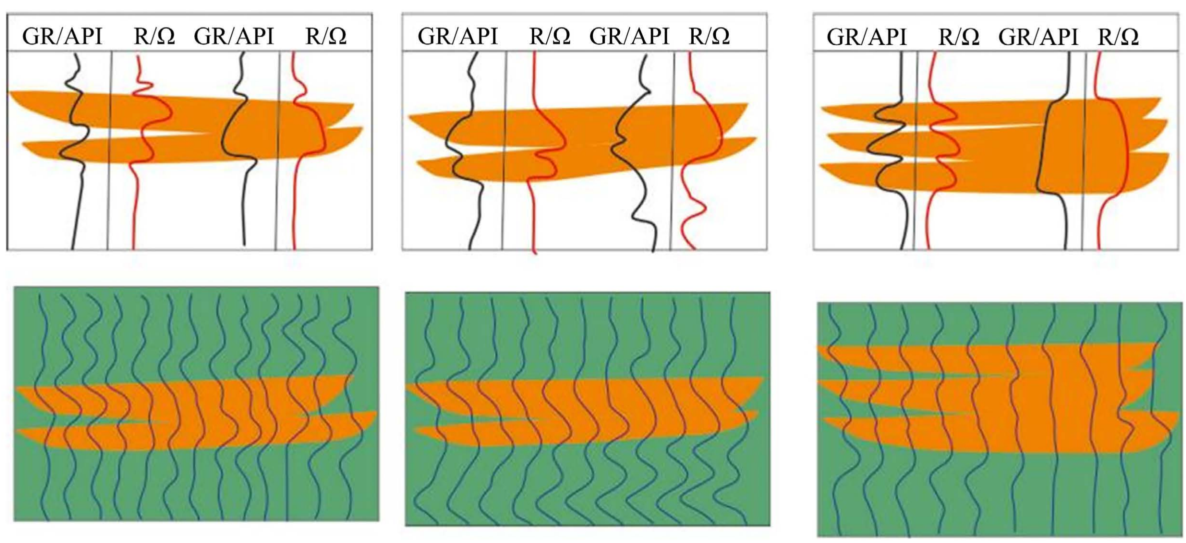

Figure 1. Forward modeling for Interlayer of three modes.

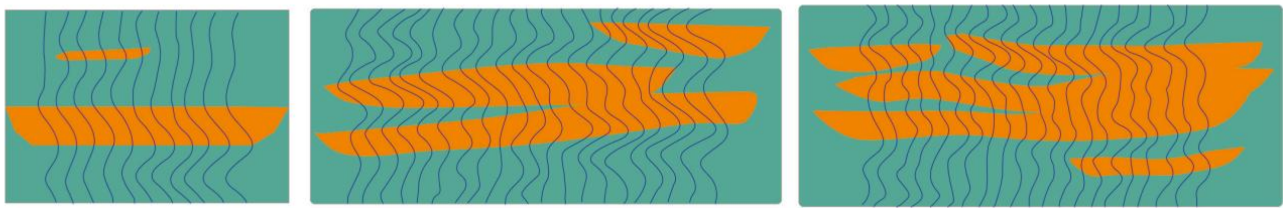

Figure 2. Characteristics of real drilling seismic profile.

3.2. The Planar Distribution of Interlay

According to the plane features of the average amplitude attributes extracted by the above method, they can be divided into three types of regions, contiguous high amplitude regions on the east and west sides, contiguous flocculent regions on the north side, and multi-feature mixed regions on the south side. Based on well data and seismic profiles, contiguous high amplitude areas represent single sand body deposits. Contiguous flocculent areas are areas where multi-stage river courses overlap and interlayer does not develop. The multi-feature mixed region represents two stages of sand body deposition. According to its plane shape, it can be subdivided into low amplitude, band-shaped high amplitude and flocculent areas, which respectively represent no interlayer, thicker interlayer and thinner interlayer referring to the real drilling seismic data. This is also consistent with the previous understanding of the profile (**Figure 3**).

After making clear the seismic profile and plane characteristics of different types of interlayers, this paper summarizes the interlayer plane description method, which integrates geology, logging and seismological specialty. Under the guidance of deposition mode and starting from the well, this method uses well-seismic combination to predict interlayer change trend, sand body distribution on the plane controls interlayer distribution range, seismic attribute determines interlayer structure, and interlayer frequency contour map corrects seismic attributes from the well. Finally, the dynamic data are used to verify and supplement the plane shape, thus obtaining the interlayer plane distribution (**Figure 4**).

4. The Application

According to the above research results, there are mainly three applications. First, the geological model of the target area has been updated to improve the precision of mathematical model fitting. After the model is updated, no matter from single well, platform or whole sand body, there is no need to modify any parameters, the precision of historical fitting has been greatly improved, and the working efficiency has also increased from 4.55 h to 0.5 h. Second, guiding the intra-layer injection of directional wells. Through interlayer plane distribution, an experimental well was selected to carry out intra-layer separate injection, and the cumulative oil increase was predicted to reach 5.5×10^4 m^3. Third, guiding the deployment of adjustment wells. Based on interlayer and frequency distribution, the following tapping strategy is formulated, horizontal wells are deployed

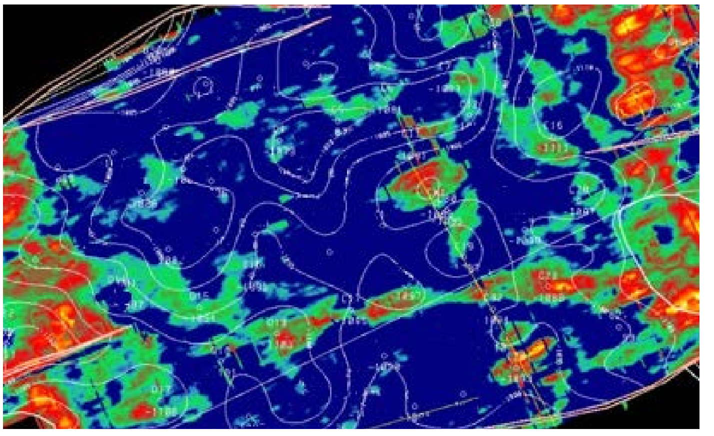

Figure 3. Plane characteristics of seismic attributes of different interlayers.

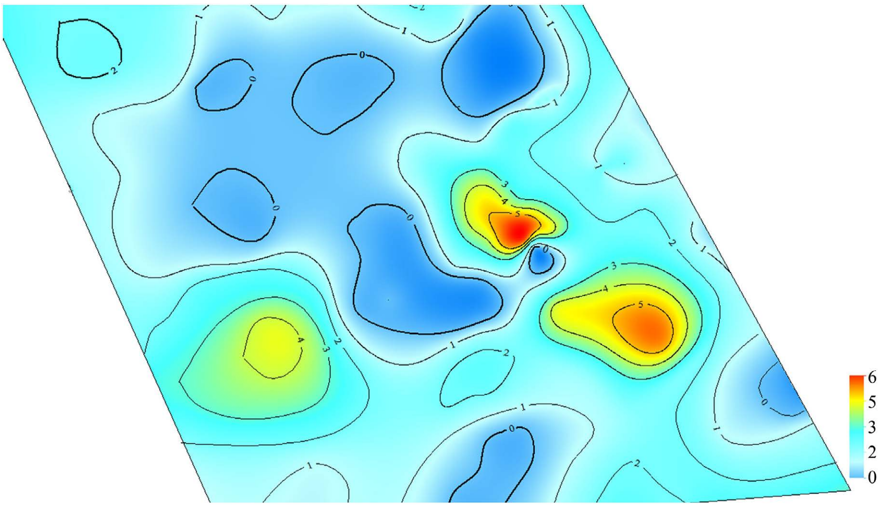

Figure 4. The planar distribution of interlay.

at the top of reservoir in no interlayer area, highly deviated wells are deployed to develop multiple sets of reservoirs in thin interlayer and high frequency areas, in the low frequency region of thick interlayer, horizontal wells are respectively deployed in upper and lower sand bodies. According to this tapping strategy, 7 adjustment wells are deployed in the target sand body, and the total initial production capacity is predicted to be 300 m^3/d, increasing the cumulative oil production by 50×10^4 m^3, and an additional economic benefit of approximately 10 million US dollars.

The above methods overcome the problem of low recognition rate of interlayer in a single sand body and propose longitudinal and planar directional recognition methods, greatly improving the recognition accuracy of thin interlayer. This method has poor recognition performance for physical layers less than 0.5 m, depending on the accuracy of logging data and seismic data resolution.

5. Conclusions

1) The argillaceous interlayer of the composite sand body is divided into three

types, including barriers between the two single layers, intercalations between the two single sands and intercalations in a single meander river bar.

2) The sensitive parameters related to interlayer are optimized, and the weight coefficients of each parameter are calculated by using the gray correlation method. The interlayer discrimination index and the comprehensive discrimination chart can be used to quantitatively identify different types of interlayer on the well.

3) For interlayers between single sand bodies, this paper summarizes three different types of deposits, establishes corresponding forward modeling, and obtains vertical seismic response characteristics of different interlayers. Through the combination of well and earthquake, the seismic profile characteristics of different interlayers and the interlayer structure represented by different plane average amplitude properties are obtained.

4) The interlayer plane description method is summarized, which integrates geology, logging and seismological specialty. Starting from the actual interlayer drilled on the well, the variation trend and distribution range of interlayer are predicted based on the characteristics of seismic plane and profile, and the horizontal distribution law of interlayer between single sand bodies is quantitatively obtained.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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