

Research on Sedimentation Patterns and Fine Prediction of Complex Intertwined Channel Reservoirs in Bozhong Block

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Abstract

The Bozhong A oilfield is located in the central waters of Bohai Sea. The oilfield is situated at the intersection of two major uplifts, Sanduotian and Chengbei, and is influenced by bidirectional sources. It has developed large and complex interwoven river channel sediments with multiple sources and water systems. The river channels are cut and overlapped with each other, and the sand bodies are developed with complex sedimentary patterns. This article focuses on reservoirs of different genesis types, using geological models as constraints, and conducts integrated well seismic joint research to explore a set of complex interwoven channel reservoir prediction techniques. Firstly, by utilizing seismic facies and seismic attributes, combined with modern sedimentary laws, the sedimentary pattern of the river facies in the Mingxia section of the oilfield was finely characterized, and a rock physical quantity plate and a matching relationship chart between seismic facies and sedimentary facies were established. By utilizing geological knowledge base, seismic facies logging and joint analysis, and attribute fusion technology, quantitative characterization of river sand reservoirs in different sedimentary genesis periods has been achieved. At the same time, by conducting research on the seismic response mechanism of composite river sand bodies with different stacking relationships, the regular characteristics between the sedimentary patterns and seismic responses of stacked river sand bodies have been established, and the reservoir connectivity between stacked river channels has been predicted. Finally, by utilizing the amplitude change rate and stacking ratio, the connectivity of reservoirs between river channels was determined. The above technology has achieved quantitative characterization of river sand bodies and connectivity between rivers, providing geological basis and technical support for efficient oilfield development.

Keywords

Fluvial Facies, Sedimentary Patterns, Geological Knowledge Base, Stacking Ratio

1. Introduction

The Bohai Oilfield has discovered a substantial amount of petroleum geological reserves through exploration in the conventional sandstone reservoirs of the Minghuazhen Formation strata in the Neogene system. The main sedimentary type is fluvial facies, and the Minghuazhen Formation strata are the primary focus of exploration and development in the oilfield. However, the geological conditions of this type of reservoir are complex, with sedimentation primarily influenced by river traction currents. The sand bodies exhibit significant lateral variations on a plane (Yao et al., 1995), and the oil and gas content of the sand bodies is complex. The study of the fine configuration of this type of reservoir has always been a constraint on the efficient development of the oilfield.

Scholars both domestically and internationally have conducted research on the complex and diverse depositional structures of fluvial reservoirs, focusing on different types of fluvial reservoirs. They have successively studied the configurations of fluvial reservoirs of various genetic types, primarily by utilizing actual production data from oil fields and combining modern sedimentation theory to conduct layered research on sand body configurations (Zhang et al., 2014; Zhu et al., 2008). By utilizing seismic, logging, and geological data, they have established reservoir depositional cycles, stratigraphic boundaries, defined and divided configuration units, and summarized reservoir configuration patterns (Dai et al., 2007). Through the application of high-precision sequence stratigraphy constraints, seismic forward modeling, and multi-attribute joint analysis, they have established depositional patterns and reservoir characterization methods for fluvial reservoir configurations (Feng et al., 2012; Sun et al., 2016). This series of measures and methods has effectively addressed the refined research of reservoirs under the dense well pattern of onshore oil fields, providing guidance for tapping the potential of remaining oil and improving oil recovery in the later stages of oilfield development (Zhang & Lan, 2013). However, for offshore oilfield development, the actual investment is high and the investment risk is significant. Under the condition of few wells, there are relatively few research methods for reservoir configuration, which severely restricts the efficient development of oilfields.

2. Geological Overview

The Bozhong A Oilfield is located in the central Bohai Sea, surrounded by the three major oil-generating sags of Shanan, Huanghekou, and Bozhong. With abundant oil supply, it possesses favorable conditions for oil and gas accumulation and

reservoir formation (Liu et al., 2014; Deng et al., 2012; Peng et al., 2009). The sand bodies in the lower segment of the Minghuazhen Formation in the oilfield are intertwined channel deposits, and the sedimentary hydrodynamic forces are dominated by traction currents (Yu et al., 2009). Research suggests that the reservoirs in the lower segment of the Neogene Minghuazhen Formation in the study area are primarily of complex fluvial facies, with distributary channel deposits being the main reservoirs. This article utilizes 25 directional wells in Oilfield A and 3D seismic data covering an area of 600 square kilometers to conduct reservoir research, with a complete set of well logging data.

Based on observations of core samples and thin sections, as well as grain size analysis, it is found that the reservoir is primarily composed of fine sandstone and siltstone, with cross-bedding and parallel bedding developed, and reservoir pores are abundant (Figure 1).

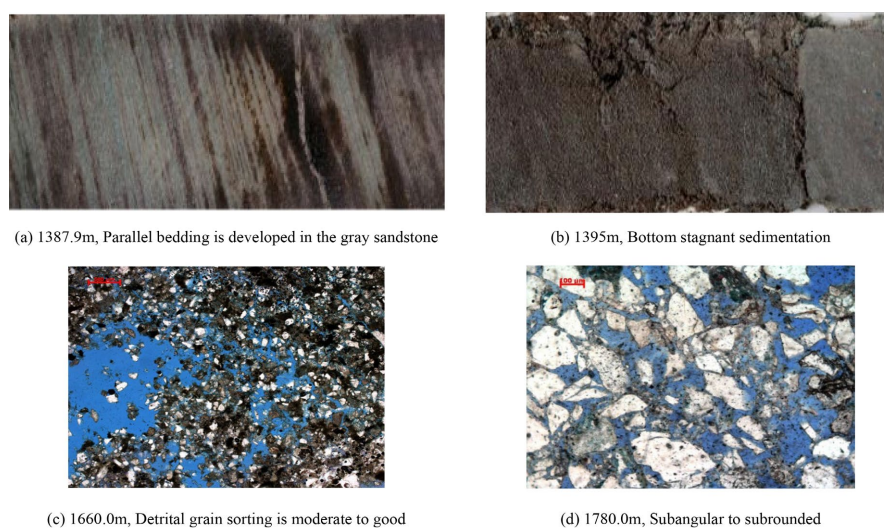


Figure 1. Core sedimentation and rock-mineral characteristics of research region.

3. Research on Sedimentary Microfacies Identification

Based on the lithological and electrical characteristics of sedimentary microfacies, the main sand bodies in this oilfield are divided into three sedimentary microfacies: channel, distributary channel, and natural levee, utilizing well logging facies and seismic reflection characteristics (Figure 2):

1) Main channel: The channel serves as the primary reservoir of the interwoven channel system, characterized by a substantial sedimentary thickness of the sand body, stable planar distribution, and favorable reservoir physical properties. The well logging curves typically exhibit box-type or composite box-type patterns, with seismic facies displaying strong amplitude and good continuity. The sedimentary thickness of the sand body remains relatively stable, generally exceeding 6 meters.

2) Branch channel: The overall appearance of the distributary channel is characterized by lag deposits developed at the bottom of the riverbed and muddy fill

in the upper part. The sediment thickness of the sand body is relatively smaller than that of the main channel, generally ranging from 3 to 6 meters. The logging curve generally exhibits a bell-shaped or boot-shaped pattern.

3) Natural levee: The sediment of natural levee is mainly composed of grayish-green mudstone, locally containing thin layers of silt deposited during flood periods. It is generally deposited on top of mudstone in the former braided channel or sand bodies at the front edge of the braided channel. The well logging curve is generally finger-like, and the thickness is generally less than 3 m.

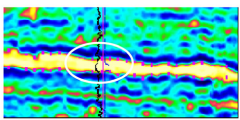
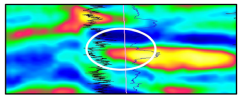
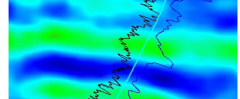
sedimentary facies	logging curve	developmental position	seismic response characteristics	reservoir thickness	physical properties
river channel		main channel	 strong amplitude	> 6m	porosity: > 30% permeability: > 1000mD
river channel		branch channel	 medium amplitude	3 ~ 6m	porosity: 25%-30% permeability: 600 ~ 1000mD
natural levee		riverbank edge	 weak amplitude	< 3m	porosity: < 25% permeability: < 600mD

Figure 2. Seismic response characteristics of sedimentary microfacies and reservoir features.

The internal configuration interfaces of reservoirs in braided river channels are generally dominated by scoured surfaces and deposition layers, with configuration units mainly developing main channels, branch channels, and natural levees. Different types of configuration units correspond to different levels of configuration interfaces, and configuration units of different levels can also be subdivided into smaller-level configuration units. The S sand body, which is the focus of this paper, is a braided river channel deposit. Combining the research on similar oil fields in the surrounding area, a geometric parameter geological knowledge base for fluvial facies reservoirs in Bozhong A Oilfield has been established, forming a correlation distribution diagram of the width-to-thickness ratio of channel reservoirs in Bozhong A Oilfield (**Figure 3**).

Based on the study of sedimentary facies, and according to the sedimentary characteristics of intertwined river channels in the region and the sedimentation patterns of modern river channels, drilling data, seismic facies characteristics, and logging facies characteristics are comprehensively utilized to determine the development stages of river channels, as well as the contact and superimposition relationships between river channels of different stages (**Figure 4**, **Figure 5**).

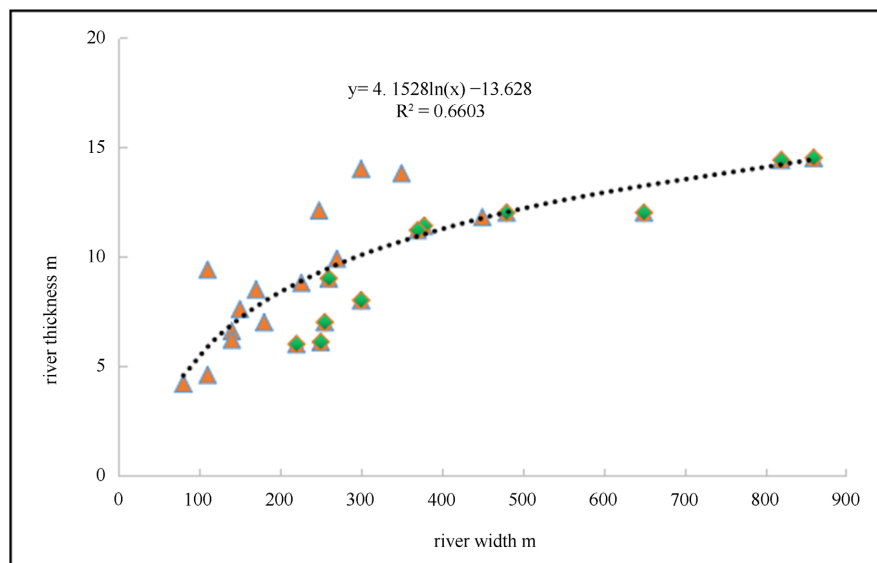


Figure 3. Distribution map of correlation between thickness to thickness ratio of river reservoirs in Bozhong A oilfield and surrounding oilfields.

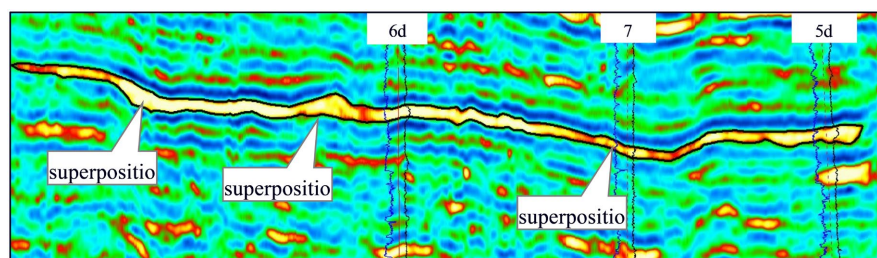


Figure 4. Crossroad sand body (same period non same source river channel).

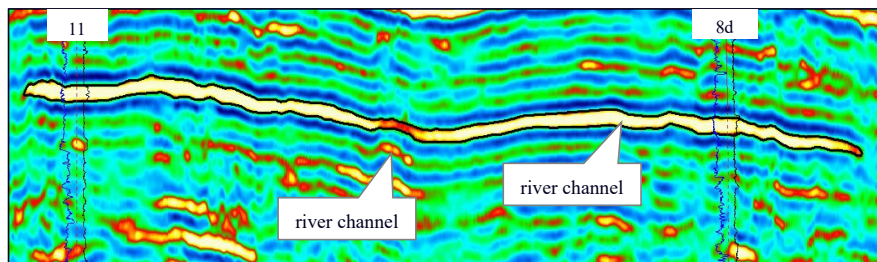


Figure 5. Overpass sand body (non synchronous river channel).

4. Characterization of Single Channel Phases and Connectivity Research

Based on the sedimentary characteristics of sand bodies from various stages and the contact patterns between sand bodies obtained from actual drilling in the study area, seismic forward modeling analysis was established using different cutting and overlapping relationships between channels. The target layer for forward modeling is a channel sand body, with a burial depth of approximately 2200 m. The sand body has a thickness of 8 - 12 m, a porosity of 32%, an oil saturation of 70%, and a shale content of 15%. The surrounding rock is mudstone. The velocity

of the sandstone reservoir is 3200 m/s, while the velocity of the surrounding mudstone is 2800 m/s. A zero-phase Ricker wavelet with a dominant frequency of 30 Hz, a sampling interval of 2 ms, and a wavelet length of 100 ms is used. This study summarized five detailed depictions of composite sand body superimposition patterns (Figure 6).

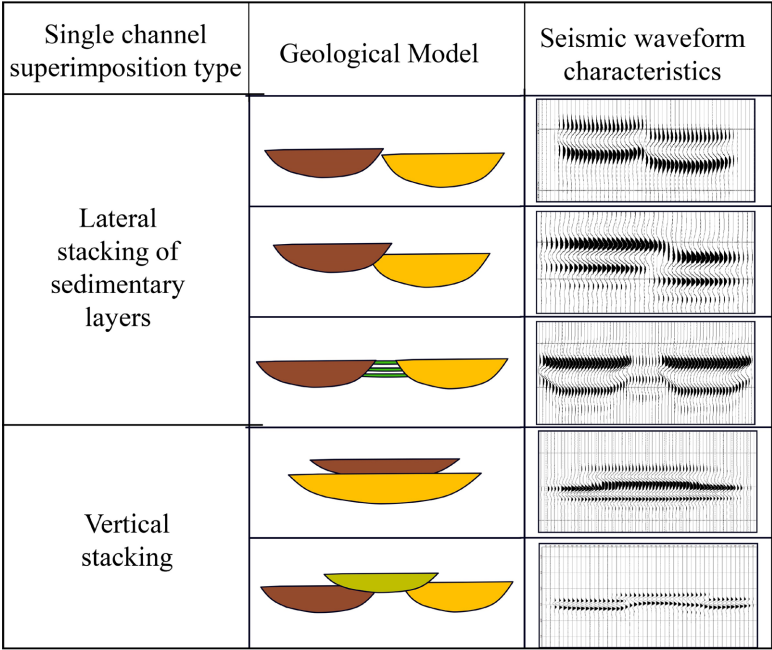


Figure 6. Identification marks for the boundary of single channel sand bodies.

In order to fully exploit the relatively high-resolution seismic information, different seismic forward modeling models were designed within the study area based on the contact relationships of different single sand bodies. The seismic-well integration indicates that conventional seismic profiles are difficult to identify the distribution characteristics of single-phase sand bodies. However, based on the waveform identification markers of different sand body contact patterns, the vertical plane superimposition relationships and boundaries of sand bodies can be better distinguished, with a high degree of well-seismic consistency. By utilizing amplitude and frequency attributes for attribute fusion, the boundaries of single sand bodies become clearer on the fused attributes (Figure 7). Based on this, the approximate range of a single structural unit can be determined, achieving a transformation from seismic phenomena to geological significance.

In the superimposition relationship of sand bodies, there are mainly two types: lateral and vertical superimposition. The higher the proportion of lateral superimposition and vertical superimposition, the greater the potential for injection-production connectivity of sand bodies.

In Figure 8, the upper left is a schematic diagram of the morphology of a composite channel sand body, with a width of a and a thickness of b . The total width of multi-phase single channel sand bodies is A , and the total thickness of multi-phase

single channel sand bodies is B . At this time, the lateral superimposition ratio is $(A - a)/a$, and the vertical superimposition ratio is b/B . From the definition of superimposition ratio, it characterizes the compactness of sand bodies within the composite channel, and this value can be used to judge the connectivity of sand bodies.

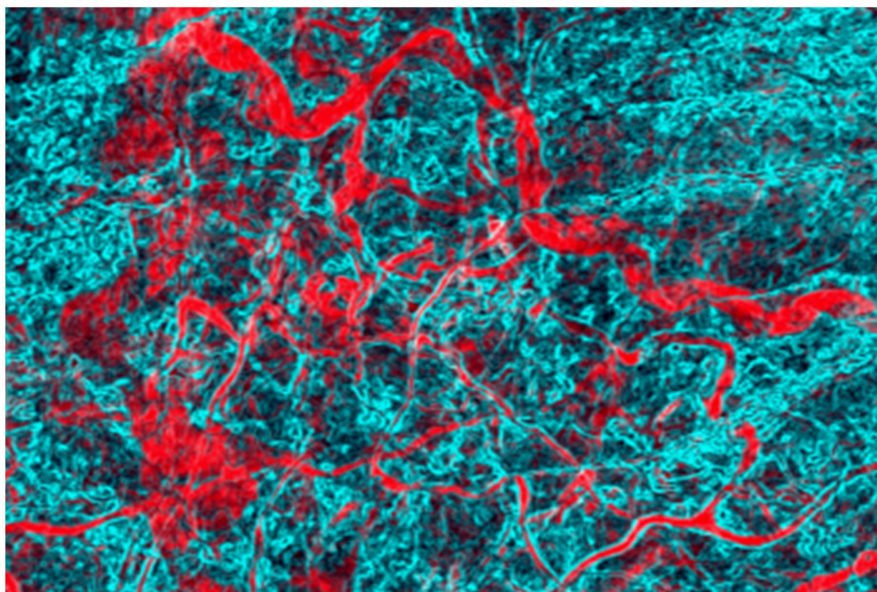


Figure 7. Fusion attribute representation of river channel period.

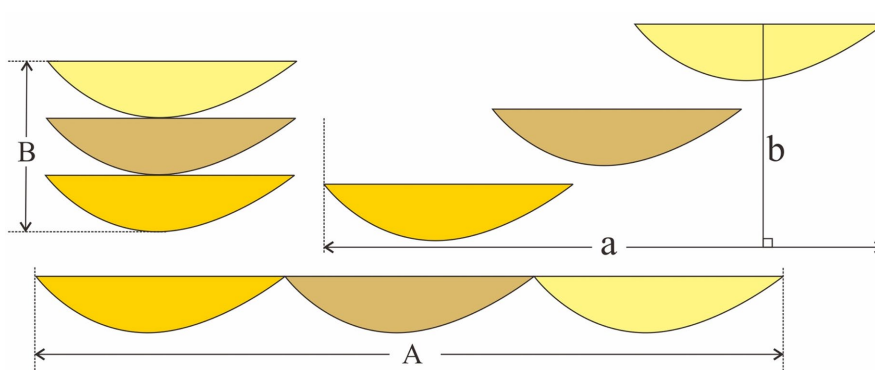


Figure 8. Schematic diagram of lateral and vertical stacking ratio of stacked sand bodies.

By plotting the correspondence between amplitude change rate and overlap ratio in a scatter plot, the fitted empirical relationship (connectivity coefficient = overlap ratio/amplitude change rate) can be used as a reference for judging the connectivity between intertwined channels. Based on the statistics of drilling encounters in 36 composite sand bodies in the oilfield, when the connectivity coefficient is less than 1.6, the probability of sand body connectivity is relatively low (Figure 9).

Under the guidance of the model, by combining well and seismic data, and interacting with planar and sectional analysis, the longitudinal distribution of sand bodies and the planar distribution characteristics of sand bodies are predicted and described (Figure 10). The S sand body is mainly sourced from the

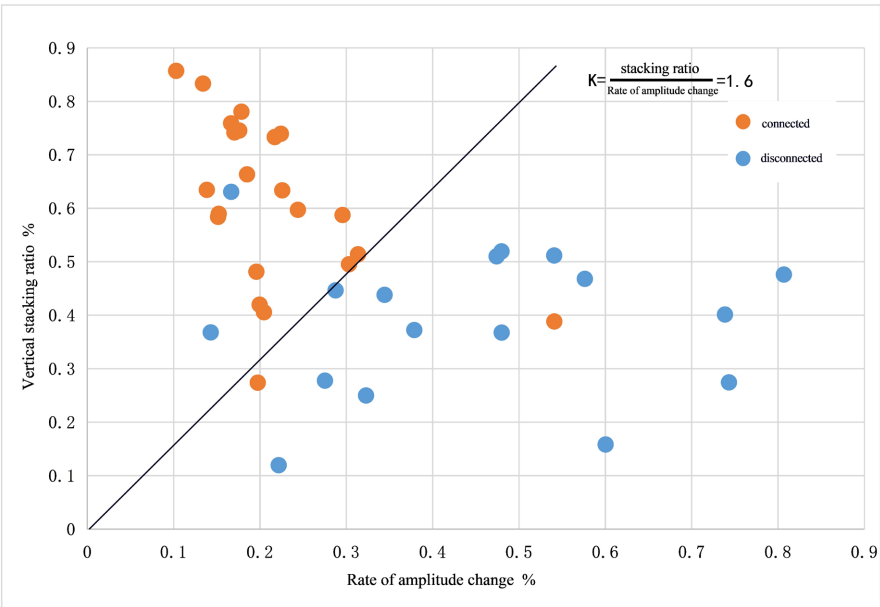


Figure 9. Scatter plot of connectivity factor for stacked sand bodies.

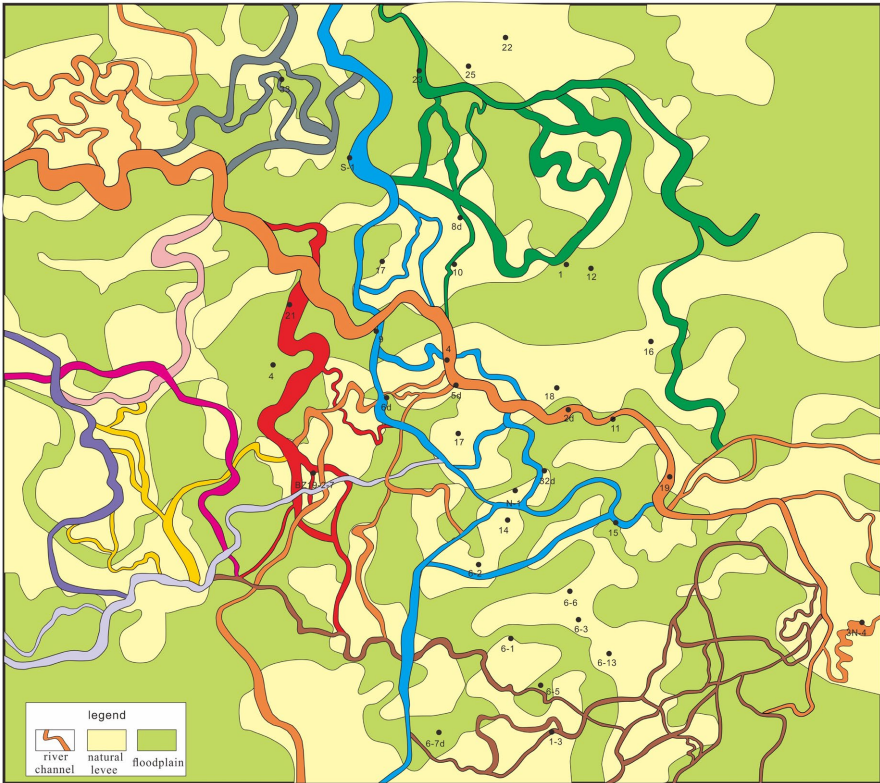


Figure 10. Plan distribution of sedimentary microfacies in S sand body.

north and is subdivided into four phases of channel sand bodies. The channels and distributary channels radiate from the north to the southwest, due south, and southeast, with the sand bodies spreading out in a lobate pattern. According to statistical analysis, the length of the S sand body's channels ranges from 310 m to

860 m, the width from 156 m to 616 m, and the thickness from 2.7 m to 9.8 m; the distributary channels mainly spread in a northeast-southwest direction, with a thickness of 1.5 m to 4.8 m. The well-drilling area mainly develops four phases of channels, which are green, blue, orange, and red channels from east to west. Through the analysis of the connectivity factor of superimposed sand bodies, it is found that the sand bodies between the four phases of channels are not connected; the connectivity rate of sand bodies between the branches of each phase of channels is less than 30%, and subsequent well locations confirm the connectivity between the channels.

5. Conclusion

1) In response to the diversity of depositional patterns in braided channel reservoirs, we have established the depositional distribution characteristics of braided channel reservoirs under different hydrodynamic conditions. Based on these distribution characteristics, we have constructed seismic forward modeling to clarify their seismic response characteristics. This provides pattern guidance and sand body superimposition patterns for subsequent fine reservoir prediction, enabling more effective fine description of braided channel reservoirs.

2) Based on the geological characteristics of the oilfield, combined with well logging and seismic facies data, the sedimentary microfacies units of the braided channel were finely dissected, and a boundary identification method for braided channel sedimentary microfacies was established. The identification characteristics of well logging and seismic facies of channels and natural levees were summarized and induced.

3) Utilizing geological knowledge bases, combined analysis of seismic and logging facies, and attribute fusion techniques, quantitative characterization of channel sandstone reservoirs from different depositional genetic periods has been achieved with fewer wells. Meanwhile, through research on the seismic response mechanism of composite channel sandstone bodies with different superimposed relationships, the regular characteristics between the depositional patterns and seismic responses of superimposed channel sandstone bodies have been established, enabling the prediction of reservoir connectivity between superimposed channels. Finally, using amplitude change rate and superimposition ratio, the connectivity of reservoirs between channels has been determined.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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