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Application of Attribute Carving Technology in Fine Description of River Facies Reservoirs in the Western Bohai Sea

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Abstract

Shallow fluvial sedimentary sandstone in the western Bohai Bay Basin is an important reservoir sedimentary type in Bohai Oilfield. During the sedimentation process, due to frequent river diversion, the interaction and rapid lateral changes of sandstone and mudstone, coupled with the limitation of seismic data resolution, reservoir prediction is difficult under sparse well network conditions in offshore oil fields. To further improve the accuracy of understanding river facies reservoirs, under the constraint of precise isochronous stratigraphic framework, the RMS fusion attribute is selected to characterize the planar connectivity of reservoirs: conducting reservoir configuration research under RMS attribute constraints to clarify reservoir genesis; selecting natural gamma attributes for genetic inversion to predict changes in reservoir properties and ultimately achieving high-precision prediction results.

Keywords

Bohai Bay Basin, River Facies, Reservoir Description, Genetic Inversion, Natural Gamma

1. Research Background

1.1. Geological Characteristics of Oilfield

With the continuous deepening of the development stage of Bohai Oilfield, the exploration and development goals of the oilfield have gradually become more refined, and the research methods have become increasingly diverse. Many new technologies have been widely applied in reservoir characterization and enhanced oil recovery research, playing an important role in the development process of Bohai Oilfield (Huo et al., 2016; Huo et al., 2007a, 2007b; Xu et al., 2009; Lv et al., 2010). This article takes the shallow meandering river facies sand body in the Bohai CFD oilfield as an example, focusing on the detailed characterization of complex structural reservoir morphology, genesis, and connectivity, and guiding the formulation of development plans.

The Bohai CFD oilfield is a small offshore oilfield, with its main fluvial sedimentary oil layers buried at depths of 1000 - 1300 m. The oilfield is a small-scale, low amplitude anticline with undeveloped internal and surrounding fault systems. During the sedimentation process of fluvial reservoirs, the river channels frequently change course and migrate, and the overall shape of the planar distribution is curved and strip-shaped, complex network like, and small-scale contiguous. The internal connectivity is complex, with an average thickness of 5 - 8 m, exhibiting extremely high porosity and permeability. The oil field is a normal temperature and pressure system, and the reservoir type is a bottom water heavy oil reservoir controlled by both structure and lithology (**Figure 1**). The viscosity of the formation crude oil is 258 mPa·s.

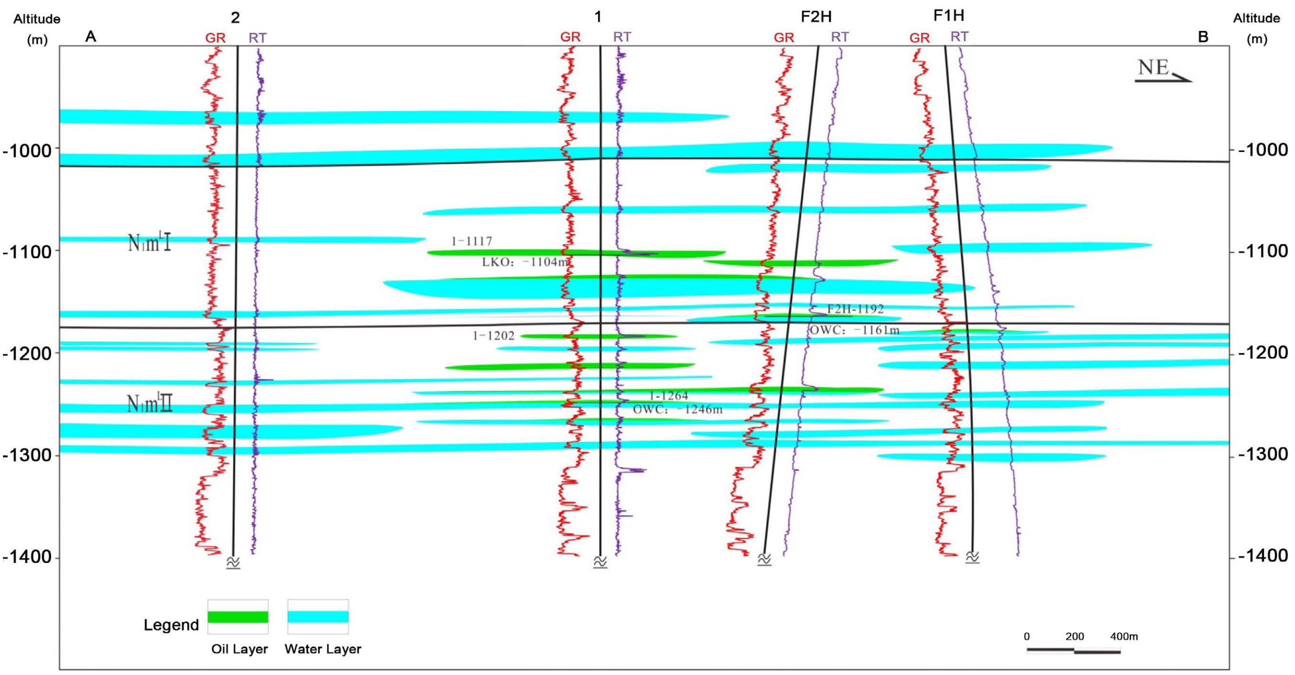

Figure 1. CFD oil reservoir profile.

1.2. Existing Problems

Due to multiple channel changes and migrations during the sedimentation process of fluvial reservoirs, the connectivity and heterogeneity of sand bodies are extremely complex. Due to the limitation of seismic data resolution, the limited number of wells in offshore oil fields, and the large well spacing, the understanding of reservoir size, structure, and physical properties cannot be achieved in one step. During the trial production process of a small number of wells in the early stage of oilfield development, the characteristics of reservoir connectivity and complex fluid systems, rapid increase in water content in oil wells, and large differences in production capacity between wells were observed. Some production wells had good production conditions, while differences in fluid systems in other production wells resulted in high water content in oil wells and poor production efficiency, posing extremely high risks to oilfield development. It is urgent to conduct precise reservoir research through the combination of well seismic analysis, to provide a detailed description of reservoir structure and connectivity, and to develop reasonable development plans for effective development and utilization of complex fluvial reservoirs to improve oilfield development efficiency and reduce development risks.

2. Ideas and Key Points of Attribute Carving Technology

Based on the geological and geophysical characteristics of fluvial sedimentation and the problems encountered during development, a general technical approach for predicting meandering fluvial reservoirs in this region has been developed. Firstly, conduct high-resolution sequence stratigraphy research and perform fine layer comparisons under the constraint of sequence isochronous framework; Secondly, the application of frequency division RGB attribute fusion technology to study the connectivity of the target layer plane lays the foundation for fine reservoir prediction; Thirdly, conduct reservoir configuration research and dissect the genesis of sand bodies under the constraints of isochronous stratigraphic framework and RGB plane attributes; Finally, to address the issue of limited well data in offshore oil fields, genetic inversion methods and the abundant natural gamma attributes of offshore oil fields are preferred to predict the distribution of river channels, lateral changes in sand bodies, and internal physical property changes from a planar perspective.

Under the guidance of the overall technical concept, in order to ensure the accuracy of the prediction results, several key issues must be noted in the detailed description of the reservoir.

2.1. Fine Layer Comparison

Fine and accurate layer comparison is the foundation of geological research and seismic method research in oilfield development. However, due to the thin sand and mudstone interbedded in river facies sedimentation, the distribution range of the reservoir on the plane is limited, and there is a lack of unified marker layers in the entire area. Under the condition of few wells in offshore oil fields, the comparison of small layers has strong ambiguity.

In this study, based on the characteristics of fluvial sedimentary facies, the calibration of stratigraphic layers (reservoirs) in the process of small layer comparison was guided by the principle of base level cycle. Under the control of marker layers, comprehensive consideration was given to the comparison modes such as river channel incision, sand body stacking, and lateral phase transition. The method of "cycle comparison, graded control, and full area closure" was adopted to complete the fine division and comparison of reservoirs. In the comparison process, the wells on the skeleton profile were first closed, then the wells that were not on the profile were closed, and finally the closure of the entire single-layer comparison was achieved, establishing a fine isochronous stratigraphic framework for the study area. The current comparison results of small layers have refined the target reserve sand unit into an isochronous stratigraphic framework. Whether it is a new well or a post drilling well, the division structure of small layers can be well compared, laying a good foundation for subsequent sedimentary microfacies research and reservoir configuration dissection.

2.2. Study on Reservoir Plane Connectivity

During the sedimentation process of fluvial reservoirs, due to frequent river diversion, the interaction and rapid lateral changes of sandstone and mudstone, coupled with the limitation of seismic data resolution, it is difficult to predict the reservoir plane range, morphology, and connectivity under sparse well network conditions in offshore oil fields, and the reservoir has strong ambiguity.

On the basis of establishing an accurate isochronous framework, this study relies on geophysical methods to characterize the development of inter well reservoirs and guide the understanding of reservoir plane connectivity. There are many planar attributes that characterize sand bodies, including amplitude, phase, frequency, etc. Amplitude attributes can highlight abnormal amplitude changes and are mainly used to characterize the boundaries and internal characteristics of sand bodies; Phase type attributes are mainly used to characterize changes in lithology and reflect the boundaries of sand bodies; The frequency attribute reflects the variation of vertical frequency and is used to characterize changes in lithology and reservoir thickness. It is sensitive to the stacking relationship of fluvial sand bodies and the response of lithological boundaries. In this study, RGB attribute fusion technology was applied and negative amplitude and attribute, as well as amplitude comparison attribute, were selected. Negative amplitude and attribute reflect the internal characteristics of the sand body, while amplitude comparison attribute reflects the boundary of the sand body. The amplitude comparison attribute was hollowed out and overlaid with negative amplitude and attribute to depict the boundary of the composite channel sand body, obtaining a more accurate sand body plane distribution shape and used to guide the study of internal connectivity of the reservoir (Figure 2, Figure 3).

2.3. Reservoir Genesis and Configuration Research

On the basis of fine division and comparison of reservoir units, by understanding the regional sedimentary background, analogical analysis of the sedimentary system in the study area, and establishing a reasonable sedimentary model. Using seismic, well logging, logging, analysis and laboratory data, guided by sedimentary models and constrained by quantitative geological knowledge base, seismic sedimentology and waveform controlled inversion are used to predict sand body distribution. The lateral boundary of sedimentary microfacies is completed according to

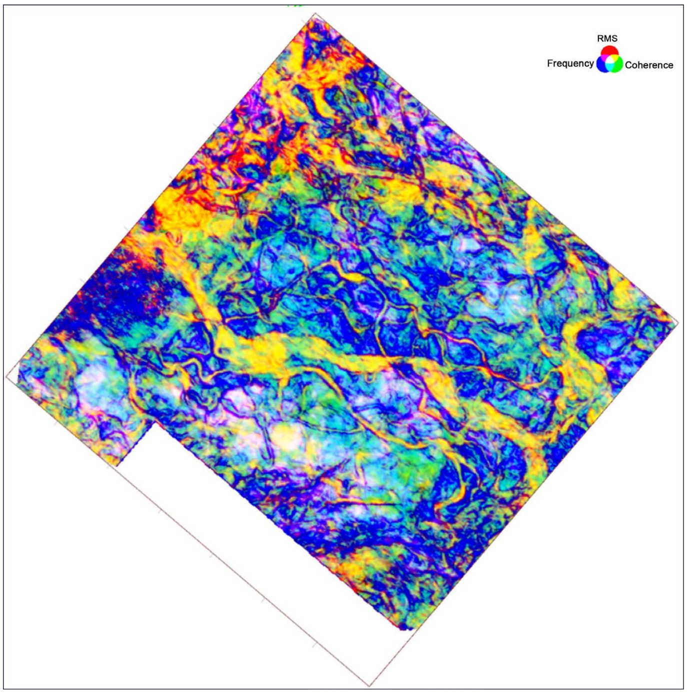

Figure 2. Seismic attribute map of main sand bodies in CFD oilfield.

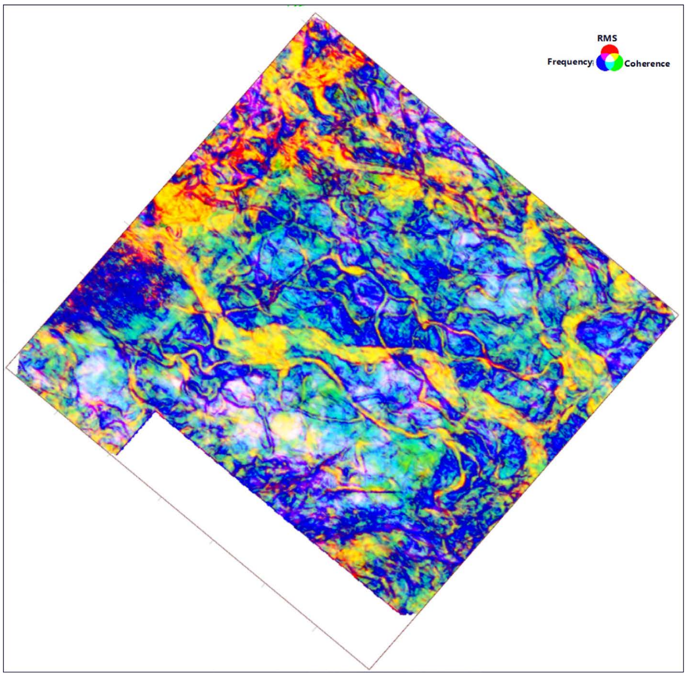

Figure 3. RGB fusion attribute diagram of main sand bodies in CFD oilfield.

the idea of "well seismic combination, hierarchical analysis, model fitting, and dynamic verification", clarifying the spatial distribution of sedimentary units inside the reservoir sand body.

Due to the good effect of RGB multi-attribute fusion in depicting the boundary of the river channel zone, the boundary of the river channel zone in the Mingxia section can be well characterized. The results can serve as an important reference for the anatomical configuration of the reservoir in the Mingxia section. Based on the geophysical characterization results, the lateral boundaries of the river channel zone and composite point dam can be well determined in terms of their distribution scale (**Figure 4**).

Figure 4. Plan of main sand body configuration in CFD oilfield.

2.4. Study on Reservoir Physical Properties

Under the condition of few wells, predicting reservoir properties based on seismic data has a high degree of ambiguity. Currently, there are various commonly used seismic inversion algorithms, each suitable for different reservoir characteristics, data quality, and target attributes. Based on the reservoir characteristics and well seismic matching relationship, combined with the limitations of offshore oil fields and logging data, this study chooses genetic inversion algorithm. As a nonlinear iterative inversion algorithm combining neural networks and genetic algorithms, genetic inversion requires only raw seismic data and well data in practical operations, without the need for wavelets and initial models. This reduces the difficulty of obtaining data and minimizes the influence of subjective factors on inversion results, while allowing researchers to focus more on the relationship between reservoir structure and seismic response; Another major advantage of this method is that the target properties of inversion are not limited to traditional wave impedance properties, but can be extended to other rock physical properties directly or indirectly related to seismic amplitude, such as density, porosity, and natural gamma. This method has been proven to have good application effects in multiple oil fields worldwide (Long & Wu, 2013; Wang et al., 2013).

Offshore oilfield development wells have the characteristics of less logging projects, so it is necessary to select the parameters that have the best correspondence with seismic data and can accurately reflect the physical properties of the reservoir as inversion targets among the limited petrophysical parameters. In view of the particularity of offshore oil fields, the exploration wells and their neutron, density, acoustic and other logging data are scarce, and the well data available for inversion are insufficient, while the development wells and their natural gamma logging data are abundant and have a good correlation with reservoir permeability. In this study, natural gamma is selected as the target attribute of reservoir genetic inversion (Figure 5), and the natural gamma inversion data volume is converted into porosity data volume, so as to obtain the internal physical property changes of sand body (Figure 6). The prediction accuracy is high after the verification of later drilling data.

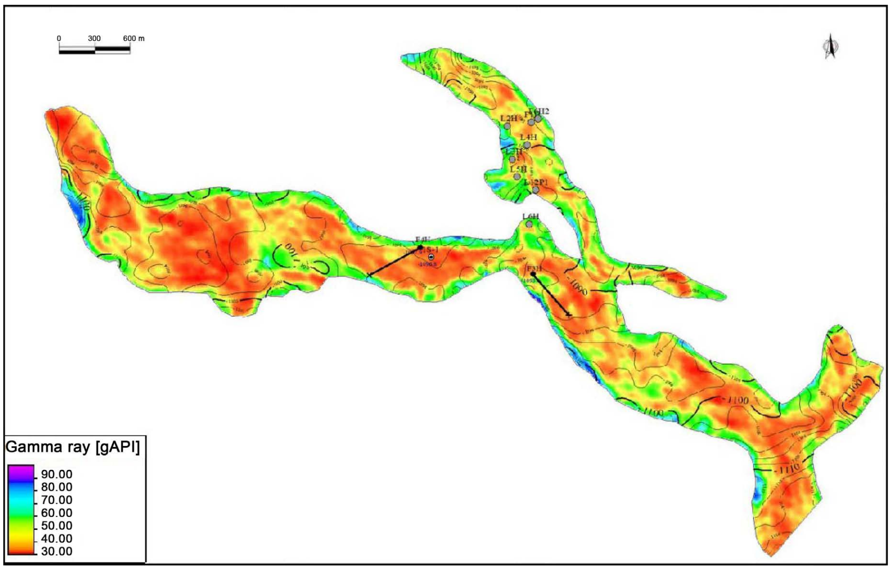

Figure 5. Natural gamma inversion attribute map of main sand bodies in CFD oilfield.

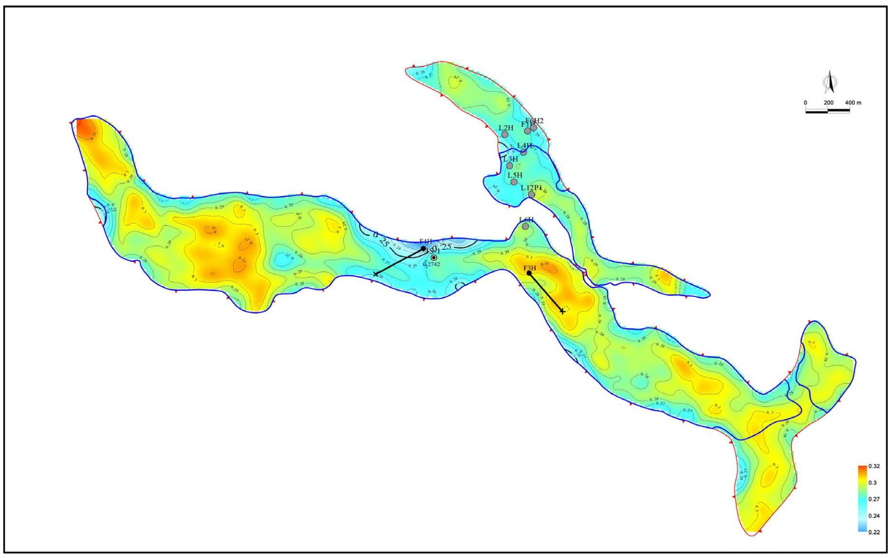

Figure 6. Plane contour map of porosity of main sand bodies in CFD oilfield.

3. Effect Analysis

In order to achieve good development results in CFD oilfield fluvial reservoirs, based on the new understanding obtained from attribute carving technology, the reservoir description and potential analysis of the oilfield are re evaluated. At present, although some wells in the main sand body have entered the high water cut stage, the well network is not yet perfect. Due to the fragmentation caused by reservoir connectivity characterization, areas without well control have great potential. Based on this understanding, in recent years, CFD oil fields have carried out fine tapping of fluvial reservoirs and implemented a number of horizontal production wells. After drilling, the accuracy of reservoir research has been confirmed, and the development effect has been greatly improved. The average initial production of a single well exceeds 100 cubic meters per day, and the recovery rate has been increased by more than 15 percentage points, achieving good economic benefits.

4. Conclusion and Suggestions

In response to the problem of low understanding and poor development effectiveness of sparse well networks in river facies reservoirs in offshore oil fields, this paper further improves the accuracy of understanding river facies reservoirs. Under the constraints of precise isochronous stratigraphic framework, RMS fusion attributes are selected to characterize the planar connectivity of reservoirs, assisting in the study of reservoir configuration to clarify reservoir genesis. Finally, natural gamma attributes are selected for genetic inversion to predict changes in internal reservoir properties, forming attribute carving techniques suitable for the geological and data characteristics of this oil field, achieving ideal results, and providing reference for the development of other similar offshore river facies oil fields.

Conflicts of Interest

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

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