

Fine Single Channel Identification Controlled by Sedimentary Facies

-Taking KLA Oilfield as an Example

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Abstract

The Neogene fluvial reservoir in the Bohai oilfield is one of the leading development horizons for increasing reserves and production in the Bohai oilfield. However, the development of offshore fluvial reservoirs is faced with the problems of thin reservoir thickness, narrow plane width, rapid lateral change, and thin well pattern. Taking the KLA oilfield as an example, this paper discusses the nuanced characterization and configuration of a single channel controlled by sedimentary facies to guide developing offshore river facies' narrow channel main control oilfield. Firstly, based on a large number of core data, the acceptable sedimentary facies identification is realized, the sedimentary model of the study area is established, the delicate calibration of logging facies and seismic facies is realized under the constraint of the sedimentary model, and a set of technical methods for nuanced reservoir characterization guided by seismic sedimentology is summarized, to realize the boundary identification of composite channel configuration and further realize the nuanced characterization of the single narrow channel. Based on this set of technology, it guides the smooth implementation of horizontal wells in the oilfield. The drilling encounter rate of the reservoir in the horizontal section of the single well exceeds 90%, ensuring the injection production connectivity and increasing the reserve production rate by more than 10%.

Keywords

Sedimentary Facies Control, Single-Channel, Reservoir Characterization, Cost Reduction, Efficiency Increase

1. Introduction

With the gradual development of oil and gas field exploration and development,

the research on sedimentary facies is becoming more and more detailed at home and abroad, and the accuracy of sedimentary facies division is becoming higher and higher [1]. Sedimentary microfacies are the most basic constituent unit in the sedimentary system, which reflects the sedimentary rocks formed under the same sedimentary conditions [2]. The viewpoint that the sedimentary characteristics of different microfacies are reflected and expressed in logging data is the basis for using logging data to identify sedimentary microfacies [3] [4].

A large number of studies show that the role of sedimentary facies in oilfield exploration and development cannot be ignored [5]. Especially at present, most domestic oilfields have entered the late stage of development, and the potential replacement and stable oil and water control are inseparable from fine sedimentary facies control [6]. With the understanding of delicate sedimentary geology, we can more clearly understand the reservoir distribution and heterogeneity [7]. We can more accurately understand the distribution of potential sand bodies [8].

Through the analysis and research of Zhenjing oilfield, Li Shengli and others show that the distribution and evolution law of sedimentary microfacies in the oilfield controls the distribution of main favorable reservoirs, so the adjustment direction of oilfield development can be comprehensively considered according to these laws [9]; Sa Liming et al. took the oil layer of group Pu I in Pubei oilfield in the south of Daqing placanticline as an example, and proved that the reservoir geological model based on the original small layer correlation and sedimentary microfacies in the middle and late stage of oilfield development cannot meet the requirements of adjusting the potential tapping and remaining oil distribution research, so it needs to be further subdivided into lithofacies units on the basis of small layer division [10]; through the research of Karamay Oilfield, Zhu Zhiliang and others show that the nuanced characterization of sedimentary facies characteristics can help to determine the distribution law of remaining oil [11]; Jiang Jianwei and others believe that the characteristics and combination of reservoir sedimentary microfacies are the main factor determining the heterogeneity of sand body and the fundamental reason for producing a large amount of remaining oil [1]; Yu Xinghe put forward a new reservoir characterization method of "microfacies guidance, phase sequence guidance, genetic quantification and combination of plane and section" through the study of domestic oilfields in the later stage of development, so as to better reflect the function and function of reservoir characterization, that is to identify the genetic characteristics and distribution laws of different reservoirs (small layers or single sand bodies for development) and solve the contradiction of oilfield development [12].

The detailed study of sedimentary facies control can understand the geometric shape, size, distribution, and vertical and horizontal connectivity of sand bodies, point out the development direction and distribution law of favorable reservoirs, guide the layout of block development well pattern and the subsequent rolling expansion and tapping potential [13] [14]. Taking the KLA oilfield as an example, fluvial facies composite narrow channel sand bodies are developed in the

oilfield, and the internal connectivity and contact relationship are highly uncertain. The plane shows that multi-stage composite sand bodies are superimposed and connected, and there are combination relationships such as interleaving type, superposition type, and migration swing type. How to dissect the spatial combination relationship within the composite sand body directly restricts the proper implementation and efficient development of the oilfield. This paper discusses the guiding role of sedimentary facies control in the nuanced characterization of reservoirs in the process of oilfield development. In the process of practice, critical technologies such as the delicate anatomy of reservoirs of complex genetic types and the identification and nuanced characterization of composite river channels under the constraints of sedimentary patterns are established. According to this technology, 11 horizontal production wells have been implemented in the fine production of composite narrow channel sand bodies, which have been put into operation for more than one year, and the average productivity of a single well can reach 180 m³/d, which provides a strong guarantee for the stable development of the oilfield.

2. Fine Anatomy Technology of Complex Genetic Type Reservoirs Constrained by the Sedimentary Model

KLA oilfield is located on the southern slope belt of Huanghekou sag and the southern edge of Bozhong 34 central structural ridge. The south side is adjacent to Laibei low uplift. The fault of the Minghuazhen Formation is developed in the oilfield, forming a series of complex fault block traps. The strata revealed by drilling in the KLA oilfield are plain Quaternary formation, Neogene Minghuazhen Formation, Guantao formation, Paleogene Dongying Formation, Shahejie Formation, and Mesozoic from top to bottom. The main oil-bearing series is the lower member of the Minghuazhen Formation of Neogene.

The lower Ming member of the main reservoir of KLA oilfield is mainly shallow-water delta deposit. Affected by the repeated migration, scouring, and superposition of shallow water delta sediments, the composite sand body is developed, the sand body is stacked longitudinally and laterally, and the internal structure of the sand body is complex. Oilfield development practice shows that the vague understanding of composite sand bodies would lead to unreasonable well location deployment and poor reserve production. After the oilfield enters the implementation stage, understanding the composite sand body in the early seismic scale and single geological model restricts the oilfield's proper implementation and potential tapping. To further understand, optimizing and implementing the exemplary reservoir is an urgent problem to be solved.

The shallow water delta distributary channel sand body in the lower section of Neogene Minghuazhen Formation in KLA oilfield is dominated by traction and drainage, the wave action of lake water is weak, the sedimentary microfacies are mainly distributary channel deposition, the estuary bar, and far sand bar are relatively undeveloped, the reservoir is formed by multi-stage channel superposition, the underwater distributary channels frequently migrate laterally and overlap each other vertically, Although sand bodies are widely distributed, there are differences in lateral connectivity. To further meet the needs of oilfield development and production and solve the above critical problems, based on a large number of analyses and research, a set of technical methods for nuanced reservoir characterization guided by seismic sedimentology are summarized, that is, firstly, the boundary of the composite channel is identified by seismic facies, and it is subdivided into single-channel level by logging facies in the composite channel. The seismic waveform characteristics are used to trace and characterize the plane distribution characteristics of a single channel. Taking the KLA oilfield as an example, this research method is described.

2.1. Sedimentary Facies Identification

During the period from Guantao formation to Minghuazhen Formation of KLA oilfield, the structure of Huanghekou sag was generally uplifted. During the lower Minghuazhen Formation (lower Minghuazhen Formation), it was mainly fluvial facies deposition. Affected by Paleoclimate and paleogeomorphology, during the deposition period of the low stand region, the lake water body was shallow, rivers controlled the regional sedimentary sand body, and the sand body structure was mainly channel-shaped sand body. The sedimentary evolution characteristics of the lower Ming section of the KLA oilfield can be attributed to the continuous retrogradation process from the meandering plain deposition of the lower Ming Section V oil formation to the lacustrine shallow-water delta deposition of the lower Ming Section IV oil formation. In the lower Ming Dynasty, the oil formation V is a meandering plain deposit. The material source comes from Kendong uplift in the southwest. The river direction is mainly southwest-northeast. Some river channels cut each other. The sediments are mainly deposited by water distributary channel, crevasse fan, and flood plain.

As the depression structure continues to rise, the lake level rises, and the lake area expands. The oil formation IV in the lower Ming formation is mainly affected by the southern provenance. Subparallel seismic facies dominate the seismic section cut along the provenance direction, and there are no "S-type" progradation reflection seismic facies on the classical delta seismic section, which reflects the gentle macro stratigraphic framework of the study area. Combined with the color combination of algae and mudstone, in the later stage of oil formation IV in the lower Ming Dynasty, KLA oilfield was in a shallow water environment, and the river controlled shore shallow lake shallow-water delta sedimentary facies was formed after the River entered the lake.

2.1.1. Sedimentary Subfacies Identification

There are two coring wells in KLA oilfield. According to the core photos of well kla-2 in the target interval (**Figure 1**), there are two main colors of mudstone in the lower section of Minghuazhen Formation: reddish-brown reflecting oxida-

tion environment and grayish-green reflecting reduction environment and the interbedding of grayish-green mudstone and reddish-brown mudstone can be seen locally. The logging data shows that the mudstone interlayer in the sand body above each well also includes four colors: green-gray with reddish-brown, green-gray with yellowish-brown, red-brown with green-gray and yellowish-brown with green-gray.

Based on the macro stratigraphic framework of the study area and the sedimentary background of the coexistence of reductive and oxidized mudstone, it can be inferred that the target stratum in the study area is the sedimentary subfacies of the lower delta plain, which is located between the average high water level and the average low water level, exposed in the dry season and submerged in the flood season. Therefore, the distributary Bay in the reductive environment and the flood plain in the oxidizing environment are developed.

2.1.2. Sedimentary Microfacies Identification

Distributary channel and natural dike: the distributary channel is rich in strong hydrodynamic structures, including uneven scouring surface, parallel bedding, oblique bedding, wedge-shaped and plate-shaped cross-bedding, etc. (Figure 2).



Figure 1. Mudstone color core photos ((a) KLA-2, 1550.7 m, Reddish-brown mudstone; (b) KLA-2, 1635.5 m, Reddish-brown mudstone; (c) KLA-2, 1548.4 m, Grayish green mudstone; (d) KLA-2, 1549.6 m, Grayish green mudstone with reddish-brown mudstone).



Figure 2. Photos of sedimentary structure cores ((a) Scouring surface, 1548.3 m; (b) Parallel bedding, 1548 m; (c) Oblique bedding, 1632.9 m; (d) Cross bedding, 1633.3 m).

In addition, the core observation also shows the positive rhythm superposition with uneven thickness, which is the superposition of multi-stage distributary channel sedimentation or the combination of distributary channel and natural dike. The logging curves of the distributary channel are mainly bell shaped and box shaped, and the natural dike is a small finger shape.

Crevasse fan: according to statistics, the logging facies of each well in the KLA oilfield mainly reflect positive rhythmic sedimentation, but there are differences in some wells. Some sand bodies are superimposed in several small funnel shapes, and the thickness of a single funnel shape is no more than 2 m. According to the analysis of logging data, the bottom of the sand body is reductive mudstone, and the top is oxidized mudstone. Based on the analogy of crevasse fan deposition developed on the east side of modern shallow water delta deposition in the south of Poyang, crevasse fan deposition at the end of the lower delta plain develops four stages of single fans vertically, with a thickness of no more than 2 m.

Distributary Bay (flood plain): the distributary Bay (flood plain) is argillaceous sediment, and the logging curve is a straight baseline.

2.1.3. Sedimentary Model

The lower Ming member of Neogene in KLA oilfield is composed of gray siltstone, fine sandstone and unequal thickness interbedding of yellowish-brown, purple-brown and some green-gray mudstone. It is a complete third-order sequence and can be further divided into lowstand domain, Lake transgressive domain and highstand domain. The lake level of lowstand system tract changes from decline to rise. The logging curve is sharp sawtooth as a whole, and the GR base value is significantly increased. It has a typical retrograde sequence. The sedimentary microfacies are mainly upper plain distributary channel and distributary Bay. The base level of lacustrine transgressive system tract rises as a whole, and the accommodation space increases. The sand body is characterized by distributary channel or crevasse fan. The logging curve is straight and low amplitude finger shape as a whole, and the parasequence is characterized by retrograde sequence, reflecting the gradual deepening of water body. During the highstand system tract period, the base level decreased slowly and the accommodation space became smaller. The channel sand body showed strong sheeting characteristics. The logging curve was low amplitude sawtooth as a whole. The parasequence showed the sequence characteristics of early aggradation and late progradation. The sedimentary facies belt was located in the plain subfacies of shallow water delta sedimentation.

2.2. River Identification and Characterization

2.2.1. Study on Identification and Characterization of Composite Channel

The lower member of Neogene Minghuazhen Formation in Bohai Sea area is a set of sand mudstone interbedded sediments in shallow lake basin, which has a low sand to ground ratio as a whole, and the sand body identification is good in earthquake [14]. In the target interval of the oilfield, the continuity of seismic data in-phase axis is good, the signal-to-noise ratio and resolution are high, and the fault is relatively clear. During the implementation of development wells, the altitude depth and actual drilling error of the top surface of the target layer predicted by seismic attribute data are generally less than 3 m, and the quality of seismic data is good. Therefore, tracking the reservoir through seismic attribute data can effectively characterize the superposition relationship of sand bodies and depict the boundary of distributary channel and main channel. In the research scope, the seismic inversion data are leveled, and then the seismic facies characteristics are used to identify and characterize the river channel on the seismic profile. Since the top boundary of the sand body is close to the top interface of oil formation V, the top interface of oil formation V is used as a marker layer for layer leveling.

Five sedimentary modes and their corresponding seismic facies characteristics are identified through seismic profile. Each river channel conforms to the seismic facies characteristics of flat top and convex bottom.

1) Separated underwater distributary channel: the profile shows that the two channels do not intersect, and the evolution order of the channel cannot be identified;

2) Cut and separated underwater distributary channel: the early channel is cut by the later channel, but the two stages of channels are not connected, and there is a thick mudstone interlayer in the middle;

3) Unidirectional natural dike connected underwater distributary channel: on the profile, the left channel develops natural dike, and the two channels are connected through the natural dike;

4) Two way natural dike connected underwater distributary channel: the profile shows that natural dikes are developed in both channels, and the natural dikes are connected together;

5) Cut and contact underwater distributary channel: on the profile, the left channel is cut by the later right channel, and the two channels are connected without mudstone interlayer.

The depiction of river boundary by seismic facies is proved to be reliable by real drilling. However, due to the influence of seismic resolution and formation structure factors such as the development of thin interbedding and interlayer, some areas are inconsistent with well earthquakes due to the development of gas layer, thin narrow channel sand body and abnormal velocity above the target layer, It is necessary to correct the depicted composite channel boundary with the help of logging data.

2.2.2. Fine Depiction of Single Channel

The composite channel shows multiple positive rhythm characteristics vertically, so part of the single sand body may be the thickness of the composite channel sand body. The internal structure of distributary channel sand body is very complex, which is mainly manifested in the vertical superposition of distributary channel sand bodies of different stages to form 10 - 20 m thick oil layer, and the interlayer is discontinuous; On the plane, multiple channels migrate laterally to

form a large-area distributed composite sand body, resulting in serious reservoir heterogeneity. On the basis of composite channel characterization, four overlapping styles of channel sand bodies are further proposed:

1) The two phases of single channel overlap vertically, but the two phases of channel do not contact, and the middle is separated by mudstone interlayer;

2) The two stages of single channel overlap vertically, the late single channel cuts the early single channel, and there is no mudstone interlayer in the middle;

3) The two phases of rivers overlap laterally, but the two phases of rivers do not contact, and the middle is separated by mudstone interlayer;

4) The two stages of river courses overlap laterally, the late single channel cuts the early single channel, and there is no mudstone interlayer in the middle part.

Vertical logging facies identification

The composite channel is characterized by multiple positive rhythms longitudinally, and there is a sedimentary intermittent surface, that is, the characteristic lithology formed between the end of one phase of continuous and stable deposition and the beginning of the next phase of continuous and stable deposition in the longitudinal sedimentary sequence, which is different from the upper and lower adjacent layers. The logging curve is mainly characterized by bench change or argillaceous response. The composite channel in this phase can be vertically divided into two phases of single channel. When drilling wells with two phases of single channel, the logging facies have obvious superposition of two phases of positive rhythm logging facies.

Plane seismic waveform tracking form

Based on the division of vertical single channel, the plane tracking of single channel is carried out by using the characteristics of seismic waveform. When the composite channel sand body has multi-stage single channel superposition, the seismic reflection characteristics change, which is related to the superposition relationship of single channel and the development position of interlayer. Comprehensive research and practice show that the superposition characteristics of single channel and its corresponding seismic response characteristics can be divided into two types.

1) The corresponding seismic waveform is simple and symmetrical when there is no multi-stage channel superposition in the first stage single channel;

2) When the two phases of single channel overlap, the corresponding seismic waveform is complex wave or the waveform is asymmetric;

In conclusion, when the two phases of single channel overlap, the seismic reflection waveform often becomes "fat" or complex wave and the frequency decreases, which is usually reflected as a low-frequency distribution area on the plane. Through the combination of well and earthquake, the plane layout of two stages of single channel is depicted.

3. Technical Achievements and Application

Using the fine description of single channel and composite channel, we can have

a more comprehensive understanding of reservoir distribution and connectivity, and make the risk of underground development clearer. Using the fine sand body characterization technology, 11 new development wells were drilled for the complex narrow channel sand body in Kenli an oilfield, with an additional reserve of 1.42 million m³ and 3 adjustment wells; Through the application of the above technology, the drilling encounter rate of the reservoir in the horizontal section of the development well is more than 92%, the average daily oil production of a single well is nearly 200 m³/d, and the cumulative oil increase exceeds the ODP design of 560,000 m³, which effectively reduces the drilling risk and maximizes the produced reserves. This technology is described by taking 1-1777 sand body as an example.

Firstly, the fine anatomy of the sand body is carried out to depict the plane distribution map of a single channel (3), so as to guide the fine implementation of the oilfield. The fine anatomy results of the sand body show that the right side of the 1-1777 sand body is formed by the interweaving of two phases of channels in different directions, and the reservoir thickness in the channel intersection area is large, rather than the branch channel deposition recognized by the previous people, For the intersection and superposition of two river channels in different directions identified on the plane of 1-1777 sand body, the upper part is partially covered by the crevasse fan. According to the river channel characterization results, the well location is optimized. In order to increase reserve production, the principle of single well through multi-channel development is adopted to maximize the benefit of single well. The horizontal well crosses multiple river channels obliquely on the plane and highly inclined wells cross multi-stage river channels vertically, Ensure the drilling encounter rate and reserve production degree of the reservoir, and the injection and production efficiency. The actual drilling confirmed that the thickness difference between the river course intersection area and the single-stage river course was large, which confirmed the accuracy of sedimentary facies research. The drilling of well a1h met the upper river course of 10.2 m, and well A2H was located in the intersection area of 22.8 m. On the plane, a8h was optimized to the upper river course area, and at the same time, it crossed the lower river course obliquely to verify the accuracy of the research results. The actual drilling confirmed that the inter channel reservoir was not developed, and pure mudstone segments were developed, It further shows that the sand body is deposited in two different river channels. At the same time, well a8h and upper channel A7h in the same period is an effective injection production well group. The production performance also confirms that the two wells are connected to form effective injection production; For well cluster A2H-A3H-A6H, wells A2H and A3H are optimized to the river channel intersection area. The two wells are drilled through the two-stage longitudinal superimposed river channel to improve the degree of reserve production. The a6h well is drilled to the horizontal water injection well in the lower river channel to use the reserves of a single river channel to supplement the formation



Figure 3. 1-1777 multi-stage channel superposition of sand body.

energy, and the production performance confirms the connection between wells to form effective injection and production. The production of production wells exceeds $150 \text{ m}^3/\text{d}$ (Figure 3).

4. Conclusion

This time, the sedimentary microfacies of KLA oilfield are finely identified through the combination of core logging and seismic, including distributary channel, natural dike, end crevasse fan, distributary bay and other sedimentary microfacies. The sedimentary model of shallow water delta plain of KLA oilfield is established, and the logging seismic identification templates of composite channel and single channel are established under the constraints of facies model. It also summarizes a set of technical methods for fine reservoir characterization guided by seismic sedimentology, that is, first identify the boundary of composite channel through seismic facies, subdivide it into single channel level by logging facies in composite channel, and then trace and characterize the plane distribution characteristics of single channel by seismic waveform characteristics. Under the constraints of the sedimentary facies model, several horizontal wells in the main sand body in the study area are implemented. The post drilling results confirm the accuracy of sedimentary facies control, ensure the drilling encounter rate and injection production connectivity of the reservoir in the horizontal section, and increase the reserve production rate of the oilfield by at least 10%.

Conflicts of Interest

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

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