

Research Article

Reservoir Structure and Remaining Oil Distribution of Meandering River Channels: A Case Study of the Y9²⁻¹ Layer in the Jingbian Oilfield, Ordos Basin

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Received 27 May 2022; Revised 9 July 2022; Accepted 15 July 2022; Published 3 August 2022

Academic Editor: Hao Wu

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The majority of the Jurassic Yan'an Formation reservoirs in the Jingbian Oilfield of the Ordos Basin have entered the middle and late stages of development, and fine characterization of reservoir heterogeneity and recognition of the remaining oil distribution are the keys to formulating comprehensive adjustment for production. The $Y9^{2-1}$ layer of the Yan'an Formation Y9 reservoir in the LZ area of Jingbian Oilfield is taken as the research object in this paper. Based on logging data, core, and other basic data, the reservoir morphology in the study area is finely characterized. Single-channel units are subdivided, and the reservoir configurations of different hierarchical levels are analyzed qualitatively and quantitatively. Finally, combined with the plane profile consistency analysis of the morphological characteristics of the sand body in layer $Y9^{2-1}$ and the injection production mode, it is concluded that there may be four distribution patterns of the remaining oil in the study area, and the composite river channel sand body dominated by the lateral superimposed mode under the inverse lateral accretion shale bed tendency injection condition is a favorable enrichment area for the remaining oil. This mode is mainly distributed in the boundary part of the different periods of single sand body superposition. These understandings not only deepen the significance of tapping the potential of the remaining oil in frequently rerouted meandering rivers but also could provide effective guidance for the further remaining oil tapping.

1. Introduction

Reservoir architecture is collectively referred to as the shape, size, direction, and its spatial superposition relationship between different levels of reservoir constituent units and interlayers in the reservoir [1, 2]. The essence of its research is to characterize sedimentary structures and evaluate reservoir heterogeneities [3, 4]. In the oil field development stage, the flow barriers at different levels within the reservoir and the seepage variability between subunits at each level have great control on the spatial distribution of the remaining oil [5, 6]. The traditional sedimentary microfacies description is difficult to reflect the lateral occlusion body and seepage difference inside the sand body, which cannot meet the prediction and potential tapping of the remaining oil in a high water-bearing oilfield. The subsurface reservoir architecture analysis is the main technical method to deepen the study of the inhomogeneity characterization of clastic reservoirs in recent years [7–12], and improve the oil and gas recovery rate [13–17], which has become a hot spot for geological research on clastic reservoirs [18–21].

The study of underground reservoir configuration is the extension and application of configuration theory originating from outcrop sedimentology and modern sedimentary analysis [22–26]. With the old oilfields in eastern China entering the middle and late stages of development, the use of 3D seismic information and well information for underground reservoir configuration research quickly attracted

the attention of domestic scholars [20, 27]. Especially when the seismic resolution cannot meet the needs of interpretation, large number of theoretical and practical results have been obtained by the multiwell prediction method under the conditions of dense well networks. This method can effectively reveal the structural characteristics of underground reservoirs in the meandering river by integrating core, logging, and dynamic monitoring information [10, 11, 14, 16, 28-32]. However, the fine anatomy of the underground reservoir configuration is not yet perfect and the specific practical work is relatively lacking for the related oilfields in Ordos Basin, which also have the problems of high water content and low degree of recovery. Therefore, the authors take the Yan 9 meandering river reservoir of Yan'an Formation in the LZ area of Jingbian Oilfield as the research object. According to Miall (1985) and other fluvial sand body configuration theories, using the rich core, logging, and other fundamental data in the area, and based on the results of previous studies on traditional multiwell sedimentary facies with small layer as the genetic unit [33–35]. Through single well identification, dense well pattern dissection, subdivision of a single-channel unit, qualitative and quantitative description of meandering river sand body distribution characteristics, deepen reservoir heterogeneity characterization. Furthermore, combined with injection and production verification analysis of the remaining oil distribution in the study area, explore the remaining oil distribution law, lay a geological foundation for the remaining oil tapping, and provide more effective guidance for future development.

2. Geological Setting

Jingbian Oilfield is located in the central part of the Yishan Slope, which is a west-dipping monoclinic slope with the simple structure of Ordos Basin [36, 37]. The exploration target formations are mainly the C2 and C6 of the Triassic Yanchang Formation and the Y9 of the Jurassic Yan'an Formation. At the end of the Late Triassic, the basin experienced an overall uplift of Indosinian tectonic movement, and the top of the Yanchang Formation was subjected to strong weathering and erosion as well as the scouring effect of floods, forming a paleogeomorphology landscape of gullies and valleys [38]. The Y9 oil formation in the study area of this thesis, the LZ area of the Jingbian Oilfield (Figure 1(a)), was deposited in this background. According to the conclusion of stratigraphic classification and sedimentary facies research (Figure 1(b)), the Y9²⁻¹ layer was developed of typical meandering river subfacies deposition, which is the research target layer of this paper. Its sedimentary microfacies are mainly channels, natural levees, floodplains, and abandoned channels [39]. The lithology is mainly blocked gray medium-fine sandstone and fine sandstone. The reservoir has medium physical properties with an average porosity of 13% and a permeability of 0.4-62.8 mD. The oil-bearing layer is affected by the single or double control of east-west low amplitude structure and lithology, and is a structural-lithologic reservoir.

The continuous lateral movement and frequent diversion of meandering rivers in the study area have resulted in the mutual cutting and interleaving of reservoir sand bodies in space, and the overlapping of multistage rivers has formed a complex internal structure of the reservoir, resulting in large vertical and horizontal changes in the reservoir, complex oil-water relationship, and severe internal heterogeneity of the reservoir [40]. At present, the comprehensive water content in the study area is 85%. Some wells have entered the stage of high water cut development. The production capacity of production wells is low and the decline is fast, resulting in great difficulty in stable production. Moreover, the remaining oil is increasingly dispersed, the difficulty of tapping potential is increasing, and the development effect is poor. However, the produced crude oil recovery rate is 15.11%, indicating that there is still a large number of the movable remaining oil underground, which is mainly blocked by the heterogeneity within the reservoir. Therefore, it is urgent to carry out the internal configuration anatomy of the underground reservoir of the main oil layer, and to clarify the internal overlapping relationship, dimensions, and heterogeneity of the reservoir sand body, to guide the remaining oil tapping.

3. Methodology

This paper is based on the idea of "Study at different hierarchical levels of reservoir configuration, characterizing qualitatively first and then quantitatively, the combination of plane and profile, verification by injection and production", firstly according to the classification scheme of fluvial reservoir configuration proposed by Miall (1985), from the perspective of analytical hierarchy process, the study of underground reservoir configuration of a meandering river in the study area is refined to the third-order configuration interface and the third-order configuration sedimentary elements under its control [41]. That is, the research object consists of a single meander belt (single channel), a single point bar, and a single lateral accretion body within the point bar (Figure 2). Guided by the architectural anatomy of meandering river deposits from the Y9 interval in Lijiawa outcrop section of the Ordos Basin [40], taking the meandering river reservoir of Y9²⁻¹ layer in the LZ area of Jingbian Oilfield as a case, systemically conduct detail study on the reservoir configuration by multiwell prediction method under the conditions of dense well networks.

For the study area, we collected the logging data of 160 wells, 15 core samples, and their lithology and physical properties test data. 56 wells were selected as the key anatomical objects, and the basic work of stratigraphic, sedimentary facies division, logging interpretation, single-well configuration unit division, and data statistical analysis was carried out, which prepared for the subsequent study.

4. Research Process and Results

4.1. Qualitative Cognition of Architecture Pattern

4.1.1. Sedimentology of Meandering River Reservoir. In the early Jurassic, the northwest Mongolian-Shaanxi ancient river was developed along the valley on the western margin



FIGURE 1: (a) Structural background and (b) stratigraphic-lithologic histogram of the study area.



FIGURE 2: Single well architecture unit division and identification of lateral accretion shale beds inside point bar.

of the study area. Under this background, the river and swamp facies strata of the Yan'an Formation were formed [42, 43]. Combined with the analysis of regional geological conditions, it is believed that the Yan 9 period in the study area is the northwest provenance system. Under the guidance of detailed stratigraphic classification and previous field outcrop sedimentary model [40], the sedimentary facies are divided by using the sand thickness/stratigraphic thickness ratio, and it is obtained that the $Y9^{2-1}$ layer in the study area developed channel, crevasse splay, abandoned channel, overback, and flood plain subfacies (Figure 3). Among them, the channel constitutes the main body of the meandering river reservoir sand body, which looks like a composite strip on the plane view, that is, the whole channel is a composite meandering belt, which is embedded in the muddy flood plain, has the characteristics of meandering river snake shape, and the sand body has good continuity. It shows that the meandering river channel was formed in the middle and late periods of the base-level surface rise, the medium to high accommodation/sediment supply (A/S) ratio results in lateral migrating of it relatively weak. The muddy abandoned channel is connected to the edge and inside of the channel, and the crevasse fans and overflow banks are sporadically distributed, which with poor physical properties and a thickness of them is less than 2 m, will be not discussed in the paper for the reservoir configuration characterization. Therefore, it is the key to reservoir configuration characterization to clarify the configuration unit division and distribution mode of meandering river channel sand in the study area.

4.1.2. Division and Spatial Architecture Characteristics of Single Meandering Belt. According to the principle of "vertically dividing channel periods and laterally dividing sand body boundaries" [20], the 2 periods of meandering belts are vertically identified in the composite channel of the study area at first. Which is marked by fine-grained sedimentary discontinuity, and its electrical measurement curve usually shows bench change characteristics, and the larger thickness of the fine-grained sedimentary, the more obvious the single

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FIGURE 3: The plane sedimentary subfacies of unit Y9²⁻¹ and distribution of composite channel sand in the LZ block of Jingbian Oilfield.

well electrical measurement curve such as SP, RT mutation, or return. Meanwhile, the vertical sedimentary spatial structure of the channel is divided into three modes according to the curve characteristics of fine grain deposition in different periods, which are isolated, weak undercutting, and strong undercutting fusion mode with connectivity from poor to good (Figure 4).

The boundary of a single-channel sand body is identified and divided into the above 2 periods of meandering belts by the well-connected profile comparison method. The identification marks such as the difference in river channel sand top elevation, the difference of river channel sand body scale, and the distribution of the interchannel sedimentary sand body and abandoned river channel are comprehensively analyzed [44–46]. Meanwhile, referred to the difference in logging curve shape and physical property distribution, the Y 9²⁻¹ layer is divided into 4 or 5 single-channel sand body units of the different periods (Figure 4). Moreover, following the lateral contact and connectivity relationship between adjacent single sand bodies, their spatial structure assembly modes are determined (Figure 5). In the study area, 7 different types mainly manifested between the adjacent single sand body of the $Y9^{2-1}$ layer, with the lateral superimposed-normal connected and vertical superimposed-good connected types as the main types.

4.1.3. Recognition of Point Bar Sand and Its Inside Architecture. Integrating well logging and core data, point bar sand is recognized according to vertical deposition and planar distribution characteristics. In the single well (referring to Figure 2), point bar sand is developed with positive rhythm features with relatively large thickness. And its inside lateral accretion shale beds are developed above 2/3 of the sand body, with the logging curve characterized by the obvious return of the micropotential curve (ML1) and the microgradient curve (ML2) to the low-value area, and the GR curve increases and SP curve slightly shifts to baseline. That is, he divided the point bar into several lateral accretion bodies. From the perspective of a sand thickness map (Figure 6), a point bar looks like a lens is the main body



Different colors represent different periods of single sand body

FIGURE 4: The profile of single sand body division and vertical overlay relationship of meandering river channel sand bodies.



FIGURE 5: The connecting modes and connectivity of single sand bodies.

of the meandering river, and is bounded by abandoned channels. It is the lunula shape abandoned channels that divide point bars of different periods into independent units.

4.2. Quantitative Prediction of a Hierarchical Configuration Units. In the quantitative research on meandering river reservoir architecture, scholars have summarized a series of empirical formulas for calculating architecture parameters through modern depositional models and fine measurements of field outcrops [47–51]. Furthermore, a large number of meandering river geological knowledge databases have been built by data statistics, satellite image interpretation observation of modern meandering rivers, and dense well pattern anatomy [16, 51-53]. At present, the quantitative prediction idea of meandering river reservoir dimensions is generally formed from the thickness of single point bar sand body to the full bank depth of the river, and then to the full bank width of the river, and finally to infer the span of the point bar [21, 48], whereas quantitative characterization carried out on different hierarchical levels of architectural elements and combined with empirical formulas of different scholars are rare. We distinctly and comprehensively realize quantitative prediction from a single meandering zone, a single point bar sand body to a single lateral accretion body of reservoir architectural elements, of which selected the 1st-period single channel of the $Y9^{2-1}$ layer (briefly named as $Y9^{2-1}$ -I sublayer) as the research aim.

4.2.1. Characterization Parameters. Bankfull channel depth (*H*), bankfull channel width (*W*), meander amplitude (meander-belt width) (W_m), point bar thickness (*H*), point bar wavelength (L_p), the dip of the lateral accretion shale beds (θ), thickness of a lateral accretion body (Δ_H), horizontal spacing of lateral accretion shale beds (ΔL), width of a lateral accretion body (W_h), etc. are shown in Table 1.

4.2.2. Single Well Thickness of Architecture Unit. Based on qualitative cognition of reservoir configuration pattern, through single well curve characteristics and well-connect profile comparison, the architecture units of the well located in the point bar of the $Y9^{2-1}$ -I sublayer are identified and divided. The statistical results show that the positive cycle thickness of the single point bar sand body in the study area is 5.9-10.4 m, with an average of about 8.0 m. The thickness range of the lateral accretion shale beds is 0.3-1.1 m, and their vertical occurrence frequency is 2-4. The lateral accretion shale beds generally divided the point bar into 3-5 lateral accretion sand bodies with a thickness range of 1.2-3.6 m, and the average thickness is about 2.3 m.

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FIGURE 6: The plane of the 1st-period single-channel sand thickness and point bar distribution of the Y9²⁻¹ layer in Jingbian Oilfield.

4.2.3. Single Meandering Belt Dimensions. The paleoriver curvature of the study area is greater than 1.7, which is derived from the core particle size analysis data and Schumm's equation [47, 54]. Therefore, the conclusion that the full bank depth of the high curvature river is approximately equal to the thickness of the point bar sand body in a single well is applicable in this study area [48, 55], and the bankfull channel width (W) and meander-belt width (W_m) can be calculated according to the empirical formula of [48, 49], respectively (Table 1). The results show that H is 5.9-10.4 m, W is 105-251 m, and W_m is 818-1974 m. At the same time, according to the empirical formula of [53], W_m is estimated about 850-1431 m. For different empirical formulas, it is speculated that the width range of a single meandering belt (W_m) in the study area is 835-1705 m, and the average width is about 1200 m by calculating the average value.

4.2.4. Single Point Bar Dimensions. Single point bar wavelength (L_p) is the characterization parameter of point bar dimensions, which can be estimated by its functional relationship with the bankfull channel width (W) (Equations (1), (2), and (3)) are, respectively, derived from [50, 51, 55]. The corresponding calculation results of L_p are 530-1274 m, 948-1390 m, and 526-1104 m. The average value of different empirical formula calculation results is obtained, and the L_p of Y92-1-I sublayer is 668-1256 m, with an average of about 950 m.

$$L_p = 0.8531 \ln(W) + 2.4531, \tag{1}$$

$$L_p = 3.03W + 0.63,$$
 (2)

$$L_p = 3.96W + 0.11. \tag{3}$$

The thickness of a single point bar sand body (*H*) is about 5.9-10.4 m; thus, we realize the quantitative characterization of point bar sand body dimensions of $Y9^{2-1}$ -I sublayer limited by the fourth-order configuration interface.

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TABLE 1: Quantitative prediction empirical formula of reservoir architecture.



FIGURE 7: Model diagram of the dip angle and horizontal spacing of the lateral accretion shale beds in the study area for the "pair of wells" method calculation. VML1: micropotential curve; VML2: microgradient curve; VPERM: permeability; VPOR: porosity.

4.2.5. Lateral Accretion Sand Body Dimensions. It is difficult to quantitatively characterize the meandering river reservoir to calculate the dimensions of the lateral accretion body, especially for the determination of the dip of the lateral accretion shale beds. There exist the empirical formula method [31, 48], the pair well method under the condition of the dense well network [55, 56], the horizontal well method [56], the direct core measurement method, the abandoned surface method, etc.

Firstly, according to the empirical formulas of the dip of the lateral accretion shale beds (θ) and the width/depth ratio (*d*) of the meandering river by [31, 48] (Equations (4) and (5)), θ is predicted.

$$\theta = \tan^{-1}\left(\frac{1.5}{d}\right),\tag{4}$$

$$\theta = 32.966e^{-0.0966d}.$$
 (5)

By calculating the ratio of bankfull channel width to depth, the d value of the $Y9^{2-1}$ -I sublayer is between 18 and 24, with an average of about 20. From Equations (4) and (5), θ is 3.5°-4.8° and 3.2°-5.8°, respectively. Different empirical formulas show that the dip of the lateral accretion shale beds is 3.3°-5.3°, with an average of 4.2°.

In addition, there are "pair wells" in the study area with well distances of about 50 m, including "pair wells" 46-02 and 45-01, 6-05 and 5-04, with distances of 86.6 m and 47.3 m, and the elevation differences (Δh) between the two wells on the same lateral accretion shale beds are 5.0 m and 3.2 m, respectively. According to the spatial geometric relationship between the elevation difference and the distance between wells (Figure 7), the dip angle of the lateral accretion shale beds in the study area is $3.3^{\circ}-3.9^{\circ}$ calculated by Equation (6).

$$\theta = \tan^{-1} \left(\frac{\Delta h}{\Delta d} \right). \tag{6}$$

By combining the above two ways of measuring the lateral accretion shale beds dip angle, it can be determined that the θ is 3.3-4.6°, with an average of 4.0°.

Furthermore, the dimensions parameters of a single lateral accretion body also include the horizontal spacing of lateral accretion shale beds (ΔL) and the width of a lateral accretion body (W_h). As shown in Figure 7, the value ΔL is related to the dip angle (θ) and the thickness of the lateral accretion body (ΔH) sandwiched by the two lateral accretion shale beds (Equation (7)).

$$\Delta L = \frac{\Delta H}{\tan \theta} \,. \tag{7}$$

It is known that the thickness of intact and single lateral accretion bodies is 1.2-3.6 m; the dip angle of the lateral accretion shale beds is $3.3-4.6^{\circ}$. It can be calculated that the spacing of the lateral accretion layer in the study area is 20.8-53.2 m, with an average of about 37.0 m.

While the value W_h could be predicted according to the conclusion of [48] that the width of a lateral accretion body is about 2/3 of the width of the bankfull channel (*W*). The information is known that the value *W* is about 105-450 m, and the W_h is 70.0-300.0 m. Thereby, quantitative characterization of a single lateral accretion sand body bounded by the third-order configuration interface is achieved.

5. Discussion

Reservoir configuration characterization is usually constrained by a quantitative geological knowledge database, and some similarities in the characteristics of similar sedimentary bodies in different regions, including spatial geometry, size, overlapping interrelationships, and plan profile consistency [57]. Hence, we can verify the rationality of this paper based on the statistical empirical formula and dense well network data to quantitatively characterize the dimensions of different levels of reservoir configuration units, by comparing the geological knowledge database of

Configuration units	Characterization parameters	Jingbian Oilfield (Y9 ²⁻¹ -II layer)	Gudong Oilfield [59] Ng5 ^{2+ 3} layer	Dagang Oilfield [16] NmII-IV layer	Kumkol Oilfield [58] M-I-1 layer
Single meandering belt	Bankfull channel depth	5.9-10.4 m	5.92-12.68 m	2.8-12.8 m	6-7 m
	Bankfull channel width	105-250 m	105-340 m	162 m	100-140 m
	Meander-belt width	835-1700 m	820-2680 m		
	Width/depth ratio	18-29	18-27		
Single point bar	Point bar wavelength	668-1256 m	600-1500 m	200-800 m	600-800 m
	Point bar thickness	5.9-10.4 m	5.92-12.68 m	2.8-12.8 m	4.0-10.0 m
	Number of lateral accretion shale beds	2-4	2-4		2-4
Single lateral accretion body	Width of a lateral accretion body	70.0-300.0 m	70-226.70 m	108 m	66-92 m
	Thickness of a lateral accretion body	1.2-3.6 m	1.16-4.88 m		4-5 m
	Thickness of a lateral accretion shale beds	0.3-1.1 m	0.2-1.0 m		0.2-0.6 m
	The dip of the lateral accretion shale beds	3.3-4.6°	4.0-9.0°	3.2-7.2°	5-6°
	Horizontal spacing of lateral accretion shale beds	20.8-53.2 m	25-46 m		50-60 m

TABLE 2: Comparison of meandering river geological database between Jingbian Oilfield and other related oilfields.

meandering rivers from previous studies, and the analogy analysis can be carried out according to the research results of the relationship between the sand body architecture characteristics and the remaining oil distribution of related oilfields to discuss the distribution pattern of the remaining oil in the study area.

5.1. Comparison of Configuration Unit Dimensions. Highly water-bearing oilfields with predominantly fluvial reservoirs, such as Gudong Oilfield, Dagang Oilfield, and Kumkol Oilfield in the South Turgay Basin, Kazakhstan, have made great progress in both qualitative and quantitative anatomy as well as the remaining oil distribution in the study of the meandering river reservoir configuration [16, 58, 59], and have formed a quantitative geological knowledge database to some extent.

The comparison of the relevant data (Table 2) shows that the quantitative data on the scale of single meandering belt and single point bar hierarchical configuration unit in this area are in good agreement, among which the scale of Gangdong Oilfield and Kumkol Oilfield is small, and the scale of Gudong Oilfield is large, while Jingbian Oilfield is in between the two, and the number of lateral accretion shale beds inside the point bar is similar. However, the dimensions of the single lateral accretion sand body in this area are relatively smaller, and thus, the internal heterogeneity is relatively stronger. Moreover, the dip angle of lateral accretion shale beds is relatively flattered and predicts the extension distance is longer.

In fact, field outcrop profile data can be used as the constraint to lower the limit for quantitative characterization of reservoir configuration. Wang Ke et al. (2021) carried out fine anatomy of sedimentary configuration and quantitative restoration of sedimentary scale on typical outcrop sections of a meandering river in Lijiawa, Yan'an area, Ordos Basin. The results show that the width of the meandering river bankfull channel in the lower segment of the Y9 reservoir in the northwestern margin of Jingbian Oilfield is 16.81~99.21 m. The meander amplitude is 86.86~512.59 m. The thickness range of a single sand body is 1.2-3.8 m, with an average of 2.0 m, which is less than the minimum value of this study. That is, corresponding to the value of bankfull channel is 105 m, the single meandering belt width is 835 m, and the single sand body thickness is 5.9 m. In summary, the configuration dimensions of quantitative prediction of meandering river reservoirs in the study area are reasonable, which not only conforms to the lower limit of outcrop profile constraint but also meets the constraint scale of the quantitative knowledge database of typical oilfields.

5.2. Architecture Characteristics of Meandering River Sand Bodies. From depositional outcrop and modern deposition, well logging as well as core data the planar distribution characteristics of single sand bodies in the different period meandering belts in the study area can be analyzed. In the $Y9^{2-1}$ -I sublayer, 4 abandoned channels and 3 point bars were identified in the plane view (Figure 8), and those numbers are 4 and 2, respectively, of the $Y9^{2-1}$ -II sublayer represents the 2nd-period meandering belt of the $Y9^{2-1}$ layer. By comparing the boundaries, point bar distribution, and the morphology of the single-channel $Y9^{2-1}$ -I sublayer and $Y9^{2-1}$ -II sublayer, it is concluded that the lateral oscillation of the channel in both periods is frequent, and the continuity of the concavity and convexity characteristic is not obvious.

To comprehensively study the meandering river sand body characteristics of the Y9²⁻¹ layer, the quantitative calculation for Y9²⁻¹-II sublayer characterization parameters is also carried out. Meanwhile, using the method of layer



FIGURE 8: The combination of plane and profile shows the sand body configuration characteristics of meandering river.

flattening along the direction of the source and vertical source to carry out the comparison of connected well profiles, respectively, for the area without well control, refers to the scale of lateral accretion body and the dip of the lateral accretion shale beds of adjacent wells for interwell prediction, and finally achieve the carving of the overall internal configuration of the meandering river reservoir. The appearance, thickness, and number of the wedge-shaped lateral accretion shale beds vary between wells depending on the hydrodynamic strength of the selected local area. In the



FIGURE 9: The main remaining oil distribution pattern in the study area under the development scheme of upper injection and upper production.

direction of the provenance, the lateral accretion shale beds is a nearly horizontal distribution on the profile (Figure 8: A to B section); while in the direction of the vertical provenance (Figure 8: C to D section), the lateral accretion shale beds accumulation incline toward the abandoned channel, and 8 or 9 lateral accretion shale beds are identified of the two-period single-channel, respectively, which are developed in the middle and upper part of the point bar, forming a "semi-connected body" [60, 61], and fluid at the top of the sand body is not connected or weakly connected. In addition, combined with logging interpretation and logging curve characteristics, the overall analysis of the profile is conducted. The results show that the distribution pattern between the single sand bodies in the selected block is dominated by lateral and vertical superimposed modes. Among them, the two sand bodies in the lateral superimposed mode have an obvious return on the logging curve, and there are fine-grained sediments between the sand bodies, which block the upward transport of oil in the lower single sand body. In contrast, there is no obvious return in the logging curve between the two sand bodies of the vertical superimposed mode, and the muddy sediments may not be preserved due to the strong erosion, and the overall resembles a thick sandstone with good connectivity, and the hydrocarbons are mainly distributed in the upper single sand body.

5.3. Analogy Analysis of the Distribution Pattern of the Remaining Oil. The plane-profile correspondence analysis shows that the sand structure of the vertical superimposed model in the study area is mainly distributed in the middle part of the superposition of the two rivers on the plane, and the sand structure of the lateral superimposed model is mainly distributed in the boundary where the two single channels are superimposed in the plane (corresponding to 60-03 and 6-04 single wells in Figure 8). According to the sand structure mode combined with the production data of the profile wells, including perforation position, initial production, current production data, closed coring wells, and logging interpretation of water flooded layer, and under the guidance of predecessors research conclusions on numerical simulation of meandering river reservoir based on reservoir architectural characterization [62], "the lateral

accretion shale beds controls the remaining oil distribution inside the point bar, and the remaining oil is mainly enriched in the upper part of the point bar", the relationship between the seepage compartment and the remaining oil distribution inside the reservoir in the study area is analyzed, and the possible remaining oil distribution patterns of the $Y9^{2-1}$ layer are summarized regarding the development factors such as the injection and extraction direction [63–72].

Since the perforation positions of the selected wells in the study area are located in the upper part of the superimposed sand body of the composite channel, only one development scheme of upper injection-upper production exists (Figure 8). From the perspective of water injection direction, the enrichment degree of the remaining oil is different between water injection along the dip direction of lateral accretion shale beds and injection in opposite direction [62]. That is, there are 4 remaining oil distribution patterns which consist of injection along with the dip of lateral accretion shale beds-lateral superimposed mode (Figure 9(a)), injection along with the dip of lateral accretion shale bedsvertical superimposed mode (Figure 9(b)), injection opposite to the dip of lateral accretion shale beds-lateral superimposed mode (Figure 9(c)), and injection opposite to the dip of lateral accretion shale beds-vertical superimposed mode (Figure 9(d)).

Due to the muddy occlusion between the single sand bodies in the lateral superimposed mode, oil distributes in both upper and lower single sand bodies. In addition, there are several lateral accretion shale beds in the two layers that lead to more remaining oil than in the vertical superimposed mode. Furthermore, referring to Zhang Jianxing's (2017) simulation results of the remaining oil distribution in point bar reservoir under different water injection schemes, it is concluded that the enrichment degree of the remaining oil is higher in the injection mode opposite to the dip direction of lateral accretion shale beds than that along the dip direction of lateral accretion shale beds. Therefore, by comprehensively comparing the four patterns of the remaining oil, the favorable enrichment area of the remaining oil in the study area is located in the composite channel sand bodies dominated by the lateral superimposed mode under the injection direction opposite to the dip direction of lateral accretion shale beds (referring to Figure 9(c), briefly named as mode c).

In addition, using the production data of the study area, the distribution characteristics of different modes of the remaining oil can be verified. The oil production and water injection well pairs, such as 6-04 and 6-02 (Figure 8, mode c), belong to the injection opposite to the dip direction of lateral accretion shale beds-lateral superimposed remaining oil distribution mode, while 45-05 and 53-01 belong to injection along the dip direction of lateral accretion shale bedsvertically superimposed mode (Figure 8, mode b), in which the oil production well 6-04 produced 1.03 t of liquid per day and 0.74 t of oil per day from November 2021, with a water content rate of 28%; while at the same time, well 45-05 produced 10.82 t of liquid per day and 2.02 t of oil per day, with a water content rate of 81%. That indicates the water flooding in the mode of injection opposite to the dip direction of lateral accretion shale beds-lateral superimposed is low. Moreover, the sand bodies dominated by the lateral superimposed mode are mainly distributed at the overlapping boundary of the composite channel, so it can be concluded that the frequent oscillation of the river channels in different periods is the main reason for the remaining oil enrichment in the meandering river.

6. Conclusions

- (1) The meandering river channel sand bodies of the Y92-1 layer in Jingbian Oilfield are vertically superimposed by 2 periods of single-channel sand bodies, and 4-5 single-channel sand bodies intersect each other in the horizontal direction. The spatial superposition relationship of the single sand body is mainly in the lateral superposition-general connected type and vertical superposition-good connected type. The point bar sand bodies with an average thickness of 8 m are developed. The number of lateral accretion shale beds was 2-4, and the thickness of the single lateral body is about 1.2-3.6 m
- (2) The dimension parameters of configuration units at different levels of the single meandering river, single point bar, and single lateral accretion body in the study area are obtained by synthesizing the empirical formulas of different scholars. Moreover, the rationality of the configuration unit scale in this paper is verified by the quantitative knowledge base of the meandering river in different regions and the field outcrop section. The qualitative analysis combined with quantitative prediction realized the planesection consistency of reservoir characterization results
- (3) The research arrived that there are four possible distribution patterns of the remaining oil in the study area, and the composite river channel sand body dominated by the lateral superimposed mode under the inverse lateral accretion shale beds tendency injection condition is a favorable enrichment area for the remaining oil. The mode is mainly distributed in the boundary part of the different periods of single sand body superposition. This research result proves that the frequent swing of rivers in different periods is the main reason for the enrichment of the remaining oil in meandering rivers. That deepens the significance of tapping the remaining oil in the meandering river reservoir and points out the direction for the further development of the remaining oil in the study area. Besides, carrying out threedimensional reservoir simulation and establishing a quantitative and predictable sedimentary configuration model would be the focus of future research, which can better serve the actual production of oilfields

Data Availability

The data used to support the findings of this study are available from the corresponding authors upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

Acknowledgments

This study was supported by the National Natural Science Foundation of China (No: 42172090) and the Jingbian Oil Extraction Plant of Yanchang Oil Field Co., Ltd. for providing samples and data.

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