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The Study of the Reservoir Inter-architecture Structure and Remaining Oil in the Eastern Part of Sabei II District

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Professional paper

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Abstract

In the Daqing oilfield, Heilongjiang Province, China, in the eastern part of the Sabei II District is a fine potential-tapping demonstration area with a long development time and complex history of well conditions. As oil exploration has entered into the high-water cut stage, the fine description of reservoir structure had a great significance to improve the effect of oil exploration. An abandoned channel is an important basis for recognizing a single river border and point bar. The top sand-shale interbedded or muddy sediments have a shelter action for the reservoir fluid, so correctly recognizing the abandoned channel is an important scientific basis for further analysing reservoir architecture and exploring the remaining oil. Due to the lateral shelter action of sand-shale interbedded with muddy sediments, the semi-connected body, consisting of abandoned and normal channel sand body, leads to an injection and production imbalance, which is namely production without injection or injection without production. It makes the top of the channel sand body become the favourable gathering place for remaining oil and a further main exploring object.

Keywords:
reservoir structure; point bar; channels; sandstone reservoir; Putaohua reservoir; Daqing.

1. Introduction

In terrestrial clastic rock reservoirs, the sand body of a point bar in a meandering river is one of the most important hydrocarbon reservoirs. At the beginning of oil exploration and development, it is the key research content (**Van de Graaff et al., 1992**). However, with the deepening of exploration and development, especially in the high-water cut stage of the internal reservoir (**Legleiter et al., 2011; Alho and Mäkinen, 2010**), due to the presence of non-permeable thin interlayers such as lateral accretion, exploring the remaining oil becomes increasingly difficult. Therefore, it has become the core work for contemporary reservoir description to accurately identify the spatial distribution form and distribution range of the point bar sand bodies (**Pearson and Gingras, 2006; Braudrick et al. 2006**). Moreover, for the lateral accretion interior the point bar, it should be clear how the distribution characteristics of contact relationships among lithology, occurrence and lateral accretion body impact on the remaining oil distribution (**Labrecque et al. 2009; Willi and Tang, 2010**). Thus, it has important significance for remaining oil to scrutinize the anatomy of architectural structure of interior point bar sand bodies (**Purkait, 2006**).

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Shizhong Ma and Yu Sun (**Ma Shizhong et al., 2008**) analyzed the formation process of meandering point dams, hydrodynamic conditions of flood events and scouring and silting mechanisms under the guidance of outcrop and modern sedimentary models. Combined with the sedimentary characteristics of the meandering point bar in the Daqing placanticline, the lateral and vertical sedimentary model of a single lateral accumulator is discussed and the overlapping sedimentary model of the point bar lateral accumulator is established. Similarly, Jingfu Shan (**Jingfu Shan et al., 2015**) used similar methods to dissect the Yangdachengzi reservoir in Jilin Oilfield on land. In view of the characteristics of the large well spacing and the sparse well pattern in offshore oilfields, Tingen Fan (**Tingen Fan, 2016**) makes full use of logging data and seismic data to quantitatively differentiate the fluid seepage shielding effect of different configuration interfaces in reservoirs, so as to solve the problems of continuity and connectivity of fluvial facies sand bodies.

2. Sedimentary characteristics in demonstration area

In the eastern part of the Sabei II District, the fine potential-tapping demonstration area for water flooding is located in the east of the pure oil zone of Saertu oilfield in the Daqing placanticline. It belongs to the delta lithologic-structural reservoir. The demonstration area mainly developed Saertu (see **Figure 1**), Putaohua and Gaotaizi oil layers for 50 years (see **Figure 2**), where the lithology is sandstone and fine-grained sandstone. In the eastern part of the Sabei II District, the reservoirs of Sa I, II, III and P II groups belong to the delta distributary plain subfacies and delta front deposition. Most of the Gaotaizi reservoirs belong to the delta outer front subfacies sand body deposition.

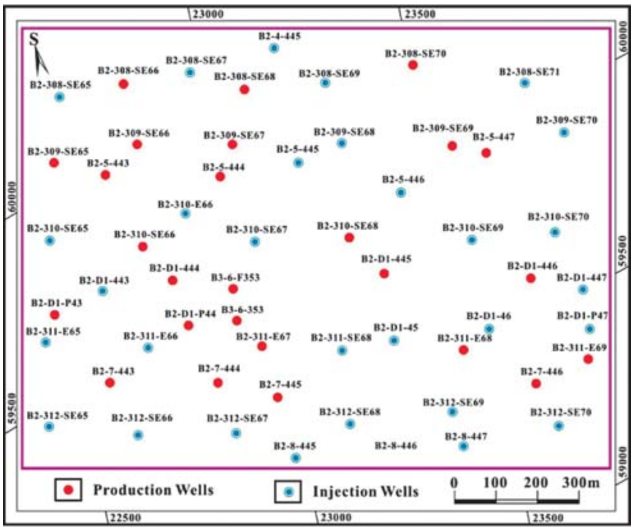

Figure 1: Distribution of wells in the study area

The distributary channel deposition sand bodies in the delta plain facies are mainly the depositional products of the channel in the flood plain and distributary plain, including near-shore, middle-shore and far-shore sedimentary types.

2.1. The far-shore deposition in the distributary channel of delta plain facies

The distributary channel extending from the north to the south mainly consists of Class I and II overbank sand as well as distributary mud. The characteristics of such sand are a large scale development of channel sand, formed by the cutting and converging of single channel sand. In the channel, the point bar and abandoned channels are well developed. Channel sand can be further subdivided into a distributary channel, the main body of distributary channel and the edge of the distributary channel. The point bar can be further divided into the main body of the point bar as well as Class I and II point bar.

2.2. The middle-shore deposition in the distributary channel of delta plain facies

The distributary channel extending from the north to the south mainly consists of Class I and II overbank sand as well as distributary mud **(Yuxi Cui, 2016; Pengfei Liu et al., 2017)**. The sand body size of further shore

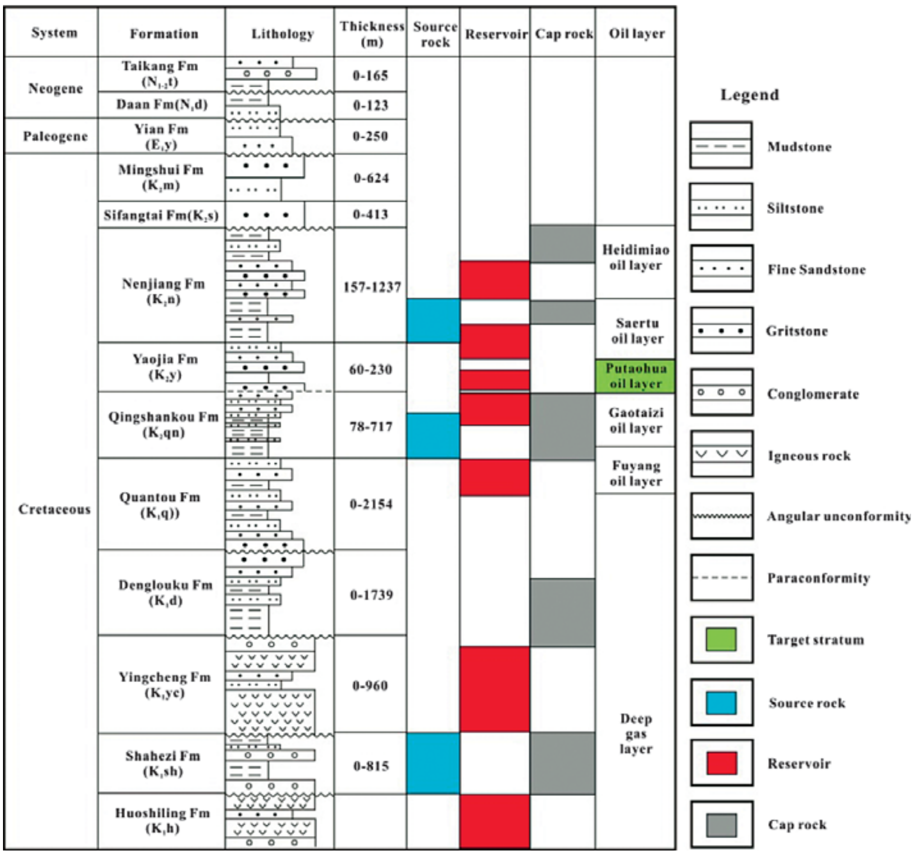

Figure 2: Stratigraphic profile in the Songliao basin

deposition is narrow. In the channel, point bars and abandoned channels are developed poorly. Channel sand can be further subdivided into the distributary channel, the main body of the distributary channel and the edge of the distributary channel.

2.3. The near-shore deposition in the distributary channel of delta plain facies

There are many types of microfacies including distributary mud, medium-sized, mini-sized and extra mini-sized distributary channel as well as Class I and II sheet sand. In this area, the distributary channel is well developed and the scale of the sand body is small. Moreover, plenty of distributary mud exists there. However, there is no sheet sand. The distributary channel extends from the north to the south.

3. Lateral accretion of interior point bar

In the meandering fluvial facies of the point bar sand bodies, the development status of internal lateral accretion is the main factor of its spatial distribution of internal remaining oil. In the process of deposition and diagenetic, uneven hydrodynamic conditions and the energy intensity causes the diverse morphology and distribution of lateral accretion. Generally speaking, the lateral extent is small and the stability is low, as the point bars of rivers in Google Maps show today (see **Figure 3**). In the dense well network, the abundant logging information of small well spacing can reliably reflect the distribution of the lateral accretion interior point bar, which provides a true subsurface model for studying the remaining oil distribution in the point bar.

The impact of lateral accretion on the oil and water migration of the reservoir depends on the interbed occurrence, density related to the number of lateral accretion bodies in the point bar, extending scale as well as the relationship between the injection and production well groups. These lateral accretion and permeability rhythmicity constitute the main factors of remaining oil formation and distribution in the point bar. For the meandering river, there are five kinds of mechanisms for the impact of the point bar sand body architecture on the remaining oil distribution as follows:

(1) Lithologic updip pinch-out shelter. The lithologic updip pinch-out shelter is formed when the lateral accretion sand body is sheltered by lateral accretion shale on both sides and is sheltered by flood plain mud in the updip direction. When the water is injected, high-pressure remaining oil with injection and no production is formed because there is no drain passage. In the downtip direction, it is connected to a lower point bar with better properties. Finally, due to lack of a driving force, the pinch-out remaining oil is formed in the pinch-out direction when there are only production wells without water injection wells in the pinch-out direction.

(2) Pinch-out remaining oil which is sheltered by cross-well lateral accretion sandstone. When the developing well distance is greater than the width of the lateral accretion mudstone, the lateral accretion sand body of the upper point bar formed by the lateral barrier and updip pinch out of cross-well lateral accretion mudstone can only be connected to the sand of a lower point bar without being directly connected to the development wells. Finally, the most significant pinch-out remaining oil which is sheltered by cross-well lateral accretion mudstone is formed.

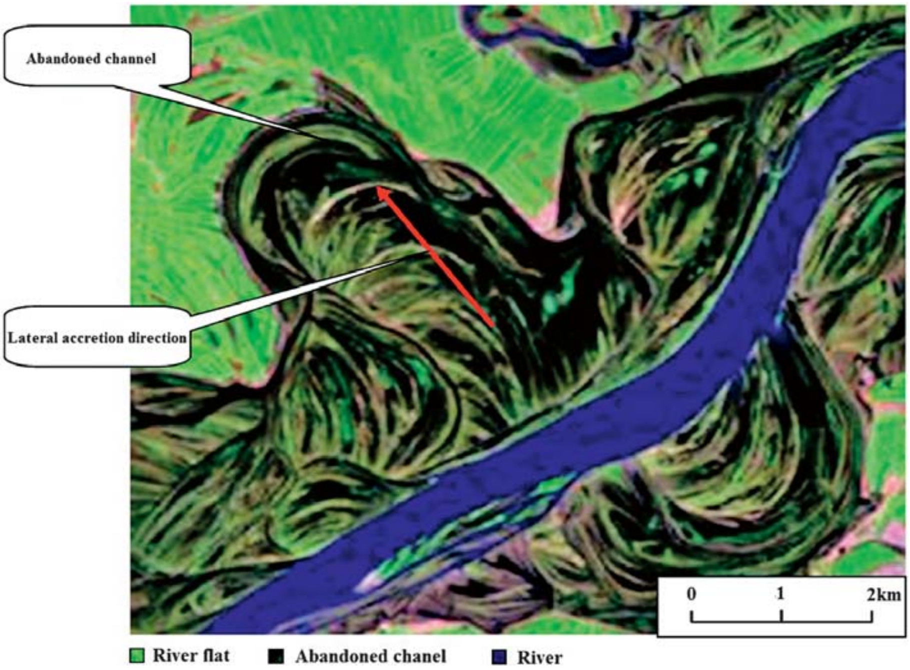

Figure 3: The dip of lateral accretion in the point bar

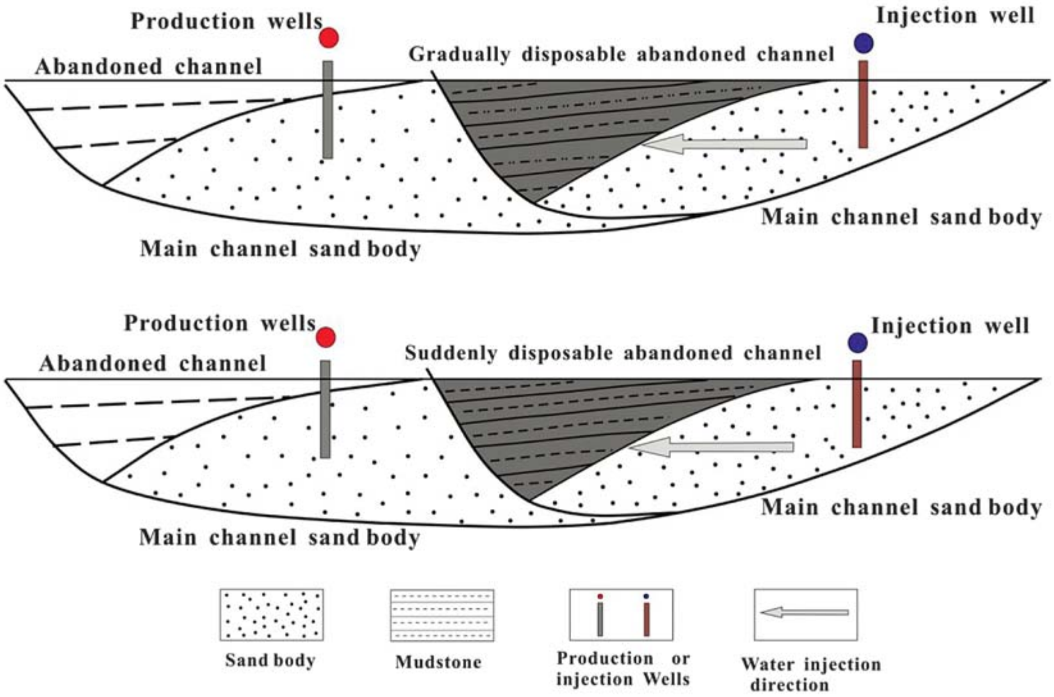

Figure 4: Mode 1 of lateral shelter action of an abandoned channel

(3) A thick reservoir was divided into numbers of thin reservoirs in an echelon arrangement (see **Figure 2**). On the other hand, the oil displacement efficiency of the same well has a great difference between the sandstone apart from dozens of centimeters with similar physical properties sheltered by the lateral accretion mudstone with only a few centimeters of thickness.

(4) The presence of the inclined lateral accretion causes different forces when the injected water moves along different directions, forming a gravitational force and resistance.

(5) The injectant shunt, confluence and rotary flow. As the oilfield water-flooding development has entered into the middle-later stage of development, seeking remaining oil has become the main content of oilfield work. In the reservoir deposition of a meandering river, the research of remaining oil distribution in the point bar attracts more and more attention. It has also become a focus to find out the shelter action of lateral accretion in point bar, which kept the injected water from spreading and formed the remaining oil reserves.

4. The lateral shelter of abandoned channel

At the bottom of the abandoned channel near the point bar, some of the active channels were developed before the channel was abandoned. Sand-mud interbed filled at the top of gradually disposable abandoned channel. Pure muddy filling was at the top of the suddenly disposable abandoned channel. Far away from the point bar, there are more and more sand-mud interbed and shale fillings, until the channel is completely abandoned. In the cross-section, the lower sand bodies are well connected with each other, while the upper part is either not connected or poorly connected. The remaining oil is located at the top of the main channel sand body.

In the process of actual oil exploration, muddy deposition at the top of a suddenly disposable abandoned channel or sand-mud interbed at the top of a gradually disposable abandoned channel can have lateral shelter action, which becomes one of the important factors affecting the relationship between injection and production. It can be summarized as two kinds of modes. One mode is an abandoned channel developed between production wells and injection wells. In this case, sand-mud interbed at the upper portion of the gradually disposable abandoned channel makes oil and water wells connect intermittently so the efficiency of production wells is not obvious. Moreover, a suddenly disposable abandoned channel can make the oil wells completely disconnect and production wells be unaffected, which makes such a phenomenon form that there are only production wells without injection wells. At last, the remaining oil exists at the top of the oil wells (see **Figure 4**). Another mode is the production wells or injection wells drilled in the abandoned channel. In a gradually disposable abandoned channel, production wells or injection wells have been less affected by the surrounding injection wells or the production wells. Furthermore, in suddenly disposable abandoned channels, production wells or injection wells can hardly be affected by the surrounding injection wells or production wells, forming an injection and production imbalance, which is namely production wells

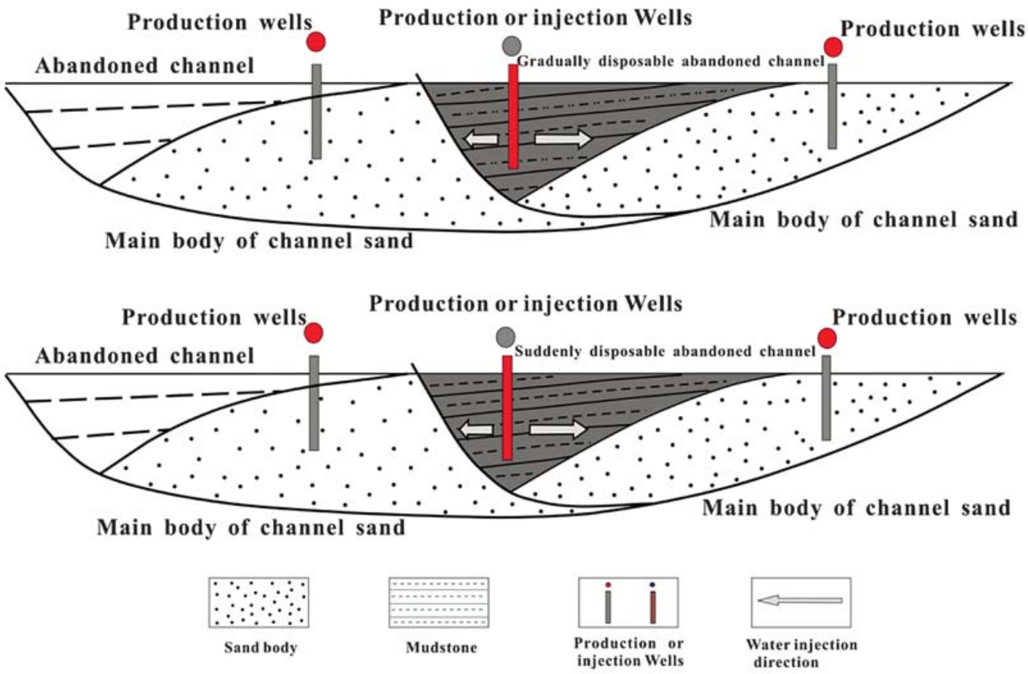

Figure 5: Mode 2 of lateral shelter action of an abandoned channel

without injection wells or injection wells without production wells (see **Figure 5**).

Thus, whether it is a suddenly or gradually disposable abandoned channel, the upper sand body is poorly developed and causes a main channel with half connectivity, which affects the swept volume of injected water. As a result, it is easy to form remaining oil at the top of abandoned channels or point bar sand body, which can be considered as the focus of studying potential-tapping remaining oil distribution.

5. Spatial distribution model of lateral accretion

The architectural structure model of an interior point bar can be divided into three categories, namely echelon, ladder and wave styles, mainly based on profile variation forms of crosscutting lateral accretion of the point bar. From the angle of the sand body connectivity, two modes can be divided, namely "fully-blocked" mode formed by lateral accretion extending along the dip direction to the bottom and "semi-blocked" mode, formed by lateral accretion layer not fully extending to the bottom. Similarly, "fully-closed" mode, formed by lateral accretion extending from the strike to the channel edge and "semi-closed" mode with a distance to the channel edge. Thus, according to the extending degree of lateral accretion along the strike and the dip direction, the spatial distribution combination can be characterized by four modes, namely the "fully-blocked" mode of the dip with the strike "fully-closed," "fully-blocked" mode of the dip with the strike "semi-closed", "semi-blocked" mode of the dip with the strike "fully-closed" as well as "semi-blocked" mode of the dip with the strike "semi-closed" (see **Figure 6**).

6. Control mechanism of remaining oil distribution

(1) "Fully-closed" mode of the strike

For the "fully-closed" mode of the strike in lateral accretion, the remaining oil distribution under control is relatively simple. The fluid flow interior point bar is mainly influenced by the degree of lateral accretion extending along the dip. For the dip "full-blocked" mode, a single lateral accretion body constitutes a relatively independent flow unit, unable to form an injection-production relationship to each other. The remaining oil of a single lateral accretion body is mainly impacted by portions of recovery. For a "semi-blocked" mode of the dip, the lower point bar sand body communicates well with each other and the physical property is fine. The injection water can be pushed along the lateral accretion on a random side. As a result, high water flooding degree at the bottom of point bar is high while the remaining oil in the mid-upper part of point bar is relatively enriched. Since there are no production wells at the top of lateral accretion, which is between injection wells and production wells, the remaining oil is more enriched and becomes a key part of mining.

(2) "Semi-closed" mode of the strike

For the "semi-closed" mode of lateral accretion deposition, as the injection water can bypass the lateral accretion from the channel edge, the injection-production re-

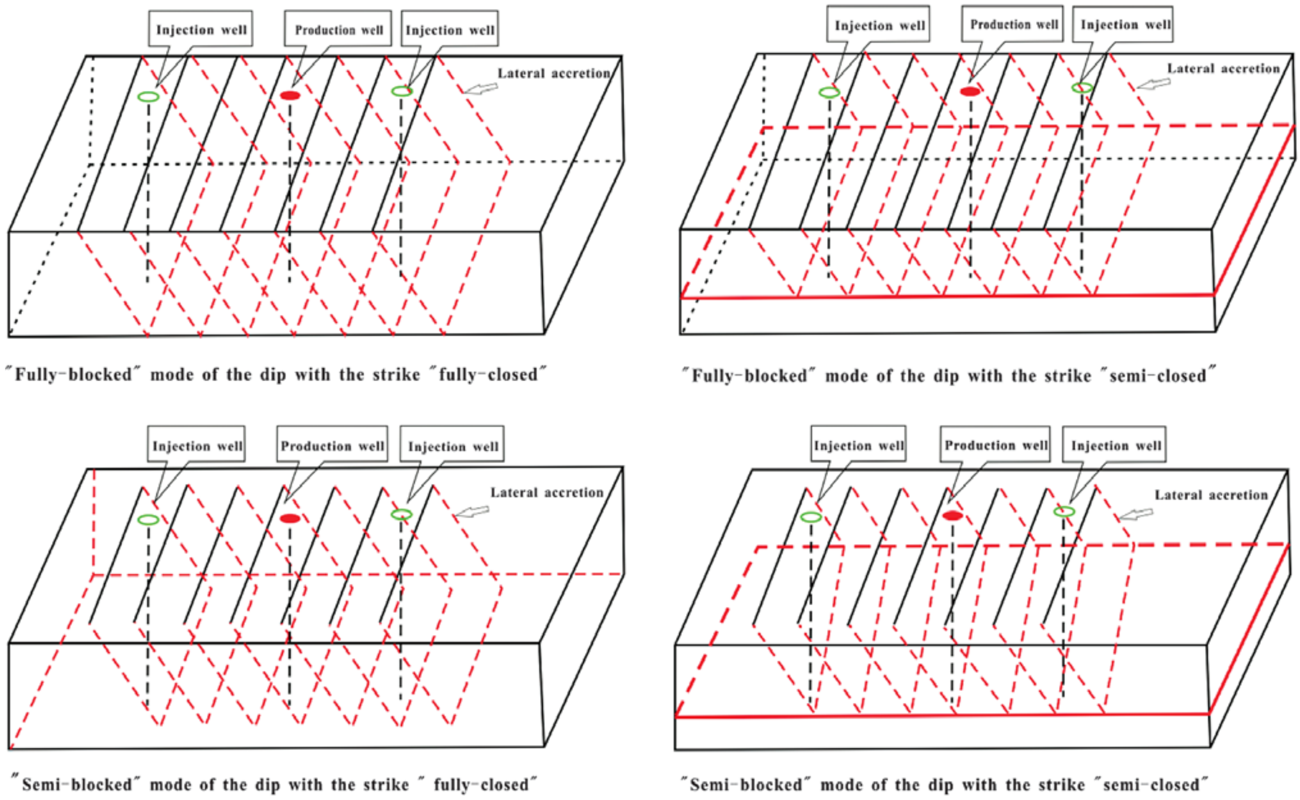

Figure 6: Spatial distribution modes of lateral accretion

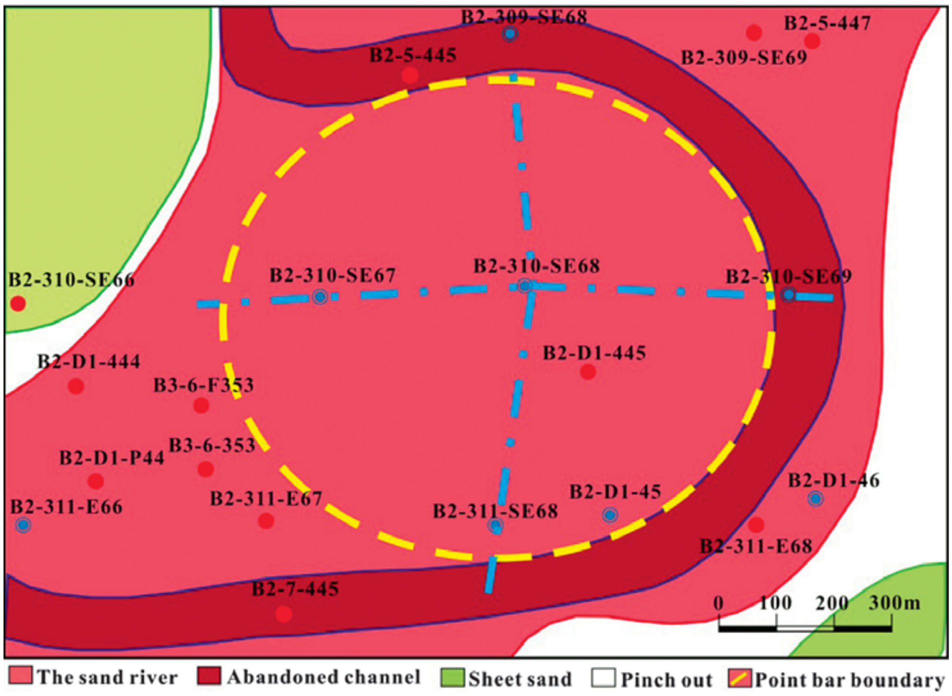

Figure 7: Profile line in typical point bar of PI1a layer in B2-310-SE68 district

lation interior point bars is more complex and the remaining oil distribution is much more complicated, while this signature can be reflected with logging data. However, as a whole, the regular feature is that the remaining oil in the point bar is relatively rich at the top of the low permeability section and is relatively poor at the bottom of the high permeability section with a serious flooding situation. When two or more lateral accretions are located between injection and production wells have little effect on the production wells, the remaining oil inside the lateral accretion is relatively rich due to its with being flooded by a lower degree of injection water. The remaining oil scale is smaller than that in the “fully-closed” mode of the strike.

PI1a small layer in B2-310-SE68 well is a typical sand deposition of a point bar (see **Figure 7**). The channel strike extends nearly from the north to the south. On the east of the point bar sand body, continuous abandoned channels are developed. As the point bar bounds, the sand body of abandoned channels is thick. There are 11 wells in the range of point bar and four wells in the abandoned channels. According to the flooding grade of sand bodies in each small layer of nearly vertical and parallel abandoned channels, injection wells with a higher flooding degree were found in the central part of the point bar. Moreover, effective sandstone at the bottom of the well is substantially high flooding. However, mid-flooding injection wells with a lower flooding degree were found in the abandoned channels and at the edge of the point par. Seen from a single well cross-sectional view, flooding degree is higher at the bottom of the point bar and is lower at the top of the point bar. Generally speaking, sand bodies of abandoned channels have a lower flooding degree and are related to internal distribution of muddy intercalation.

In summary, sand bodies of the point bar mainly have two aspects to control over the remaining oil distribution. One aspect is the distribution of its internal lateral accretion and another aspect is the abandoned channel distribution of the point bar boundary. The influence mechanism is a lateral shelter action of a low-permeable or non-permeable layer. Since the lateral accretion of a meandering river, accretion in the internal part of point bar and the top of abandoned channels are oblique to the sand level, which might form a closed intersection area and conducive to a large concentration of remaining oil.

7. Conclusions

This paper takes the Sabei II District of the Daqing Oilfield as the research object and accurately identifies sand bodies of a point bar in the object layers. By quantitatively studying the internal building structure of sand bodies, analyzing the influence mechanism of remaining oil distribution and studying the distribution of potential remaining oil, we obtained the following understandings and conclusions:

1. The sand body of the point bar is the result of lateral erosion and undercut in rivers. In the convex bank of the meandering river, the lateral accretion was formed by lateral aggradation. Cyclical changes in hydrodynamics are the main factors forming laminate accretion of the point bar. In the three elements of the point bar, laminate accretion is the most important factor in the study of the internal archaeological structure of the point bar and is also the facies marks of the point bar sand body. Distributions of lateral accretion, development scale and spatial distribution characteristics led to sand body heterogeneity in the point bar, to a certain extent, which affected the flow characteristics of the fluid inside the sand body.

2. Since sand bodies of the point bar were affected by the uncertain factor of the river hydrodynamic conditions, a complex set of distribution patterns were formed during the deposition. It brought great difficulty in identifying underground sand bodies of the point bar with logging data which reflects lithologic characteristics, while the data disperses geographically. With the fact that the logging data is distributed, according to modern deposits and outcrops, sand bodies of the point bar have its own spatial sedimentary characteristics in lithology, bedding structure and rhythm. By summarizing various deposition characteristics of its space and establishing identification marks, comprehensive identification methods from the point, line, surface and body space were formed, which provided a scientific basis for formulating the oilfield development program and adjusting potential measures of remaining oil.

3. Reservoir sedimentary facies, heterogeneity, internal interbed and abandoned channel distribution are the main factors affecting the sand body distribution of remaining oil in the point bar. Remaining oil is likely to be remained in thin sand layers with low permeability, lateral accretion or pinch-out areas of abandoned channels. In the test area, there are five types of the remaining oil mainly including the remaining oil at the top of channel sand body, the remaining oil in the thin sand layers, the remaining oil in the low permeability zone and lithologic pinch-out zone, the remaining oil formed by interlayer interference as well as the remaining oil formed by incomplete injection recovery.

4. The lateral accretion has a great impact on the internal flow characteristics of a sand body mainly showing in its occurrence, distribution density and extending scale. By increasing the formation measures in the measuring direction of the point dam, the oil well production is increased by 8% ~ 13%. Due to the distribution effect on the internal lateral accretion, local remaining oil is richly formed by the lateral accretion shelter at the top of the point bar. It will be of great practical significance to tap the potential remaining oil in these parts to improve ultimate oil recovery.

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SAŽETAK

Studija unutarležišne arhitekture te preostale nafte na primjeru istočnoga dijela strukture okruga Sabei II

Polje Daqing, u provinciji Heilong, Kina, smješteno je u istočnome dijelu okruga Sabei II. To je prostor s velikim potencijalom, ali i dugom poviješću bušenja i razradbe ležišta ugljikovodika. Kada je proizvodnja nafte došla u razdoblje pridobivanja s velikim količinama vode, pojavila se potreba za ponovnom analizom strukture ležišta, a kako bi se povećao udjel nafte u fluidu. Težište je stavljeno na napuštene paleokanale, odnosno riječna korita i sprudove. U krovini se nalaze taložine šejla ili glinjaka koji su ujedno izolatori, dok su ležišta u napuštenim kanalima predstavljena izmjenama pješčenjaka i šejla. Takva izmjena može predstavljati i bočne granice migracije, ali i tek djelomice povezana ležišna tijela ispunjena pješčenjakom podrijetlom iz napuštenih ili glavnoga riječnoga paleokanala. To utječe i na utiskivanje te planiranje proizvodnje, a zbog održavanja proizvodnje bez dodatnoga utiskivanja ili utiskivanja bez odraza u proizvodnji. Zaključeno je kako je najplići kanalski pješčenjak najpovoljnije ležišno tijelo za pridobivanje preostalih količina nafte te uopće za daljnju razradbu.

Ključne riječi:
struktura ležišta, sprud, kanal, pješčenjačko ležište, ležišta Putaohua, Daqing

Authors contribution

Shangming Shi (PhD) accomplished partial figures. **Shangming Shi** and **Huanlai Zhu** (PhD) provided assistance in the side-deposited interlayer inside the dam. **Hengshuang Li** (MSc) and **Senlin Gan** (BSc) established spatial distribution models of lateral shelter and lateral intercalation of abandoned rivers. **Zhiwei Zhai** (PhD) provided support in the controlling mechanism of the remaining oil distribution.