

Research Article

Analysis on the Main Controlling Factors of Oil Accumulation in Putaohua Reservoir of long12 Block in Daqing Longhupao Oilfield

Tianye Li ^{1,2}, Lei Zhang ³, Xuejuan Zhang,³ Dandan Wang,^{4,5} Xiangxiong Jin,³ Qianhao Yin,³ and Yue Wu³

¹Shengli Oilfield Company of Sinopec, Chunliang Operation Area of Oil and Gas Downhole Operation Center, Binzhou 256504, China

²School of Earth Science, North East Petroleum University Daqing, 163711, China

³Chongqing University of Science and Technology, School of Petroleum Engineering, Chongqing 401331, China

⁴State Key Laboratory of Petroleum Resources and Prospecting, China University of Petroleum, Beijing 102249, China

⁵Unconventional Oil and Gas Science and Technology Research Institute, China University of Petroleum (Beijing), Beijing 102249, China

Correspondence should be addressed to Lei Zhang; zhlkeyan@163.com

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Long12 block of Longhupao oilfield is located in the western slope area of Qijia-Gulong Sag, which lay in the central depression of Songliao basin. Recent exploration and development shows that Putaohua oil layer has great potential storage. However, the block is located in the ring concave fault zone, with complex geological background and extensive low resistivity oil layers and water layers of high resistivity, resulting in an unclear condition of reservoir forming and oil-water distribution rules of Putaohua oil layer, which deeply restricts the pace of increasing storage and production of the oilfield. In this study, the data of logging, logging, drilling, analysis, and testing are adopted to study carries out a reservoir forming conditions such as source rocks, reservoirs, caprocks, traps, and migration conditions. Meanwhile this study discuss the main controlling factors of Putaohua reservoir formation in combination with the law of oil-water distribution, so as to provide a geological basis for clarifying the reservoir forming law of long 12 block and the prediction of favorable target areas.

1. Introduction

Longhupao oilfield is located in the western of Qijia-show Gulong Sag in the central depression of Songliao basin. In recent years, exploration and development has shown that the Putaohua oil layer in Longhupao oilfield has abundant oil and gas resources around the area, and also it is one of the main oil layers explored in recent years, showing good reservoir increasing potential. However, the Putaohua oil layer has a wide range of low resistivity oil layers and high resistivity water layers, so the identification of oil and water is a big problem, and the previous research scope is too large to accurately reflect the oil and gas enrichment law of each block in Longhupao oilfield. Because this block is located

on the ring concave fault zone, and the geological background is complex, the reservoir forming conditions and the oil-water distribution law of this block are ambiguous. This problem deeply restricts the pace of increasing oil reserves and production and greatly restricts the further integration of exploration and development in this area too.

In order to deepen the geological understanding of this area, clarify the main controlling factors of reservoir formation and the law of oil-water distribution, and break through the bottleneck of exploration and development, this paper takes the Putaohua oil layer in long12 block of Longhupao oilfield as the research object, guided by the theory of petroleum geology, and comprehensively utilizes the data of logging, well logging, well drilling, physical property analysis,

oil test, and other data to carry out the analysis of reservoir forming conditions such as source rocks, reservoirs, caprocks, traps, and migration, combined with the law of oil-water distribution, the main controlling factors of oil and gas accumulation are discussed. It provides a geological basis for clarifying the law of oil and gas migration and accumulation and the prediction of favorable target areas, which is of certain significance for further exploration and development in this area.

The formation of oil and gas reservoirs is the result of the matching of reservoir forming conditions such as “source, reservoir, cap, circle, and transportation” in time and space. Therefore, the research on the evaluation method of oil and gas reservoir forming conditions has always been a hot spot for scholars.

In the past two decades, the theory of oil and gas transportation has become a hot spot of research, especially in the unconformity [1], faults and fractures [2, 3], skeleton sand body [4, 5], and other transportation system types, which comprehensively combed the paths and conditions of oil and gas migration, accumulation, and dissipation [6]. At present, the evaluation methods of transportation conditions are mainly the following four methods: the method of combining geological analysis with geochemical parameters, basin simulation method, sequence stratigraphy method, and sedimentary diagenesis method.

Fujie et al. [7] used the method of combining geological analysis with geochemical parameters to study the faults in Tazhong area and analyze the transportation conditions and reservoir control in this area. Xiaorong et al. [8] used basin simulation method to simulate and analyze the process of oil and gas transportation. The third method is mainly to divide migration and accumulation units according to the characteristics of formation cycles, and establish a transport model using parameters such as sand to ground ratio and sealing [9–11]. The fourth method is based on sedimentary microfacies, combined with diagenesis, to analyze the physical properties of the current reservoir and restore the ancient properties [12], and comprehensively analyze the dominant channels of oil and gas migration.

In fact, the research on the main controlling factors of oil and gas accumulation is to determine the most critical factors affecting oil and gas accumulation in the study area through analysis and research on the basis of studying the oil and gas accumulation in a certain area. Since the sixties of the last century, the idea of “source control theory” has begun to sprout. Chaoyuan believes that oil generating areas control the distribution of oil and gas. After investigating about 200 oil field hydrocarbon generating areas and the law of oil and gas distribution, he summarizes the application scope of “source control theory”, and establishes three levels according to the distance from the source rock area [13–16]. Xiaoguang and Jiayu [17] first proposed that the accumulation and distribution of oil and gas depend on the distribution of regional caprocks in time and space, and the theory of source cap jointly controlling oil and gas accumulation began to develop. They discussed that the dynamic and static relationships between source caps play a role in the enrichment of oil and gas [18–20]. Many

scholars have done a lot of research on fault reservoir control from different aspects [21–23]. The most popular view is that the fault activity period, fault transport type and fault sealing are closely related to oil and gas accumulation [22–24]. Up to now, petroleum geologists have reached a consensus on the research of oil and gas accumulation. In petroliferous basins, the coupling relationship and space-time matching of reservoir forming elements such as “source, reservoir, cap, circle, and transportation” all play a certain role in controlling oil and gas accumulation. Each basin has different structural characteristics, so the role of reservoir forming conditions is different, but it is often the main controlling factor of reservoir forming that determines the success of exploration [25–29].

2. Materials and Methods

2.1. Oil-Water Distribution Characteristics. Oil-water distribution is a comprehensive reflection of the matching of reservoir forming conditions in time and space. A clear understanding of the law of oil-water distribution can provide a basis for more accurate research on the main controlling factors of reservoir formation. Therefore, this paper collates and analyzes the data of logging, logging, and oil testing in the whole area, establishes the oil-water identification chart based on the oil-water identification standard, interprets the oil-water in the study area, and then analyzes the spatial distribution characteristics of oil-water in Putaohua reservoir in the study area.

2.1.1. Identification Standard of Oil-Water Layer. Mudstone, argillaceous siltstone, and siltstone interbedded with different thickness are mostly developed in Putaohua oil layer. The study area has a large scope. According to the separability of structure and logging data, the study area is divided into three parts. The logging responses of different blocks are different. According to the logging, logging, and oil testing data, the response parameters such as deep resistivity and acoustic time difference related to fluid properties are selected, and the “zoning” method is used to establish the fluid identification template of Putaohua reservoir.

- (1) Logging response characteristics of Putaohua oil and water layers

Table 1 gives a summary of the range of logging response values of oil layer, oil-water layer, and water layer of Putaohua oil layer. It can be seen from the chart that the sensitive curves of oil-water layer identification in Putaohua oil layer are deep side, relative value of natural potential, acoustic time difference and neutron.

- (2) Establishment of grapevine flower oil and water layer identification chart

Using the optimized sensitive logging response and parameters, the step-by-step stripping method is adopted, that is, the water layer, oil (gas) layer, and the same layer are divided first, and then the oil layer and the same layer

TABLE 1: Summary of logging response value range of oil layer, oil-water layer and water layer of Putaohua oil layer.

| Curve and parameters | Fluid properties | | |
|----------------------------|------------------|-----------------|-------------|
| | Oil layer | Oil-water layer | Water layer |
| AC ($\mu\text{s/m}$) | 224-285 | 223-281 | 236-280 |
| RLLD ($\Omega\text{-m}$) | 13-35 | 8-23 | 6-17 |
| ΔSP | 0.16-0.67 | 0.1-0.6 | 0.0-0.35 |
| Δgr | 0.1-0.75 | 0.1-0.5 | 0.1-0.6 |
| RILD ($\Omega\text{-m}$) | 8-23 | 5-21 | 5-12 |
| CNL (%) | 15-24 | 10-23 | 11-20 |
| DEN (g/cm^3) | 2.3-2.5 | 2.3-2.6 | 2.3-2.55 |

are divided, so as to establish the interpretation chart and standard of oil and water layer.

(1) Zone 1:

There is less oil test data in the first water layer of the division, so it is considered to establish the identification chart of oil layer and the same layer based on the oil test and production data.

Using the oil test data of 35 layers of 16 wells, the discrimination chart of RLLD- ΔSP oil layer and the same layer is established, including 20 oil layers, 13 oil-water layers, and 2 water layers. The accuracy of the chart is 94.3%. The discrimination standard is shown in Table 2.

Using the oil test data of 29 layers of 15 wells, the discrimination chart of RLLD-CNL oil layer and the same layer is established, including 16 layers of oil layer and 13 layers of oil-water layer. The accuracy of the chart is 100%. The discrimination standard is shown in Table 3.

Using the oil test data of 35 layers of 16 wells, the RLLD-AC oil layer and the same layer discrimination chart is established, including 20 oil layers, 13 oil-water layers, and 2 water layers. The accuracy of the chart is 97.1%. See Table 4 for the discrimination criteria.

(2) Zone 2:

There is less oil test data in water layer 2 of zone, so it is considered to establish oil layer and same layer identification chart based on oil test and production data.

Using the oil test data of 35 layers of 19 wells, the RLLD- ΔSP oil layer and the same layer discrimination chart is established, including 13 oil layers, 19 oil-water layers, and 3 water layers. The accuracy of the chart is 96.9%. The discrimination standard is shown in Table 5.

Using the oil test data of 28 layers of 14 wells, the discrimination chart of rlld-cn1 oil layer and the same layer is established, including 10 oil layers, 17 oil-water layers, and 1 water layer. The accuracy of the chart is 96.3. The discrimination standard is shown in Table 6.

Using the oil test data of 30 layers of 17 wells, the rlld-ac oil layer and the same layer discrimination chart is established, including 11 oil layers, 16 oil-water layers, and 3 water layers. The accuracy of the chart is 92.6%. See Table 7 for the discrimination criteria.

(3) Zone 3:

Using the oil test data of 41 layers of 19 wells, the rlld-cn1 oil-water layer discrimination chart is established, including 9 oil layers, 222 oil-water layers, and 10 water layers. The accuracy of the chart is 80.5%. See Table 8 for the discrimination criteria.

Using the oil test data of 44 layers of 22 wells, the rlld-ac oil layer and the same layer discrimination chart are established, including 9 oil layers, 23 oil-water layers, and 12 water layers. The accuracy of the chart is 77.3%. The discrimination criteria are shown in Table 9.

Using the above oil-water interpretation standards, the oil-water interpretation of the wells in Putaohua oil layer in the study area was carried out. After reviewing the oil-water interpretation results with the existing oil test results, it was found that the average accuracy of the oil-water identification chart reached 89% (as shown in Table 10), which laid a foundation for the study of oil-water distribution characteristics.

2.1.2. Vertical Distribution Characteristics of Oil and Water.

Based on the above research results, the established oil-water chart is used to interpret the oil-water in the whole area, and the oil-water distribution characteristics are clarified through the oil test data and logging interpretation results. Putaohua oil layer develops many types of reservoirs vertically, such as oil layer, oil-water layer, water layer, and dry layer; The vertical oil-water distribution of a single well can be divided into the following eight types: pure oil layer (G30), upper oil layer and lower oil-water same layer (I172-s4), oil-water same layer interbedding (I173), oil-water same layer (I172-1), oil-water same layer and water layer interbedding (t233), upper oil layer or water-water same layer lower layer (G33), upper oil-water same layer lower layer (t36-2), and water layer (G41).

To sum up, the overall vertical distribution of oil and water in the study area is complex, with both upper oil and lower water and upper and lower water oil.

2.1.3. Horizontal Distribution Characteristics of Oil and Water.

In terms of structural characteristics, the study area is divided into five structural zones, which are the northern gentle slope area, the central gentle slope area, the steep slope area, the deep concave area, and the Longhupao structural area, respectively. According to the productivity statistics of the wells in each division, the productivity of each division of Putaohua formation is different, but there are industrial oil flows (Figure 1). On the whole, the production capacity ranges from high to low in steep slope area, middle gentle slope area, Longhupao structural area, deep depression area, and Northern gentle slope area. According to the situation of each division, the steep slope area is dominated by middle oil wells (0.5 t/d ~10 t/d) and high-yield oil wells (>10 t/d. In the middle gentle slope area (1-5 t/d), the production capacity is less, there is only one low-yield oil well, and the most high-yield oil wells. The productivity wells in Longhupao structural area are similar to those in steep slope area, but there are few oil producing wells (5 -10 t/d). The

TABLE 2: Discrimination criteria.

| Fluid classification | Criterion | Symbol |
|----------------------|---|--|
| Oil layer | $RLLD \geq 13.7$ and $\Delta SP \geq 0.2$ | |
| Oil-water layer | $8.5 < RLLD < 13.7$ and $0.14 < \Delta SP < 0.2$ and $RLLD > 8.5$ | ΔSP —Relative value of spontaneous potential, RLLD—Deep lateral resistivity value, $\Omega \cdot m$ |
| Water layer | $RLLD \leq 8.5$ or $\Delta SP \leq 0.14$ | |

TABLE 3: Discrimination standard table.

| Fluid classification | Criterion | Symbol |
|----------------------|---|----------------------|
| Oil layer | $RLLD \geq 13.7$ and $\Delta SP \geq 0.2$ | |
| Oil-water layer | $RLLD < 13.7$ $RLLD \leq 2.13 * CNL - 22.51$ | CNL—Neutron value, % |

TABLE 4: Discrimination standard table.

| Fluid classification | Criterion | Symbol |
|----------------------|--|--|
| Oil layer | $RLLD \geq 13.7$ and $RLLD \geq 1.2538 * AC + 320.89$ | |
| Oil-water layer | $8.5 < RLLD < 13.7$ and $AC > 245$ Or $0.731 * AC + 187.54 < RLLD < 1.2538 * AC + 320.89$ and $AC \leq 245$ | AC—Acoustic time difference, $\mu s/m$ |
| Water layer | $RLLD \leq 8.5$ or $RLLD \leq 0.731 * AC + 187.54$ | |

TABLE 5: Discrimination standard table.

| Fluid classification | Criterion | Symbol |
|----------------------|--|--|
| Oil layer | $RLLD \geq 16.5$ and $\Delta SP \geq 0.2$ | |
| Oil-water layer | $10 < RLLD < 16.5$ and $\Delta SP > 0.14$ Or $0.14 < \Delta SP < 0.2$ and $RLLD > 10$ | ΔSP —Relative value of spontaneous potential, RLLD—Deep lateral resistivity value, $\Omega \cdot m$ |
| Water layer | $RLLD \leq 10$ or $\Delta SP \leq 0.14$ | |

TABLE 6: Discrimination standard table.

| Fluid classification | Criterion | Symbol |
|----------------------|--|----------------------|
| Oil layer | $RLLD \geq 16.5$ and $RLLD \geq 4.0714 * CNL - 60.857$ | |
| Oil-water layer | $RLLD < 16.5$ Or $RLLD < 4.0714 * CNL - 60.857$ | CNL—Neutron value, % |

TABLE 7: Discrimination standard table.

| Fluid classification | Criterion | Symbol |
|----------------------|--|--|
| Oil layer | $RLLD \geq 16.5$ and $RLLD \geq 0.8438 * AC + 225.75$ | |
| Oil-water layer | $0 < RLLD < 16.5$ and $AC > 248$ Or $0.615 * AC + 160.77 < RLLD < 0.8438 * AC + 225.75$ and $AC \leq 248$ | AC—Acoustic time difference, $\mu s/m$ |
| Water layer | $RLLD \leq 8.5$ or $RLLD \leq 0.615 * AC + 160.77$ | |

productivity of the deep depression is slightly lower than that of the steep slope area, the middle gentle slope area and the Longhupao structural area, and the middle oil wells

are the main ones; the northern gentle slope area has poor production capacity, and the number of low production wells is the largest.

TABLE 8: Discrimination standard table.

| Fluid classification | Criterion | Symbol |
|----------------------|--|---------------------|
| Oil layer | $RLLD \geq 15$ and $RLLD \geq 3.53 * CNL - 53.82$ | |
| Oil-water layer | $11.5 < RLLD < 15$ and $CNL < 20$ Or $2.35 * CNL - 35.88 < RLLD < 3.53 * CNL - 53.82$ | CNL—Neutron value,% |
| Water layer | $RLLD \leq 11.5$ or $RLLD \leq 2.35 * CNL - 35.88$ | |

TABLE 9: Discrimination standard table.

| Fluid classification | Criterion | Symbol |
|----------------------|---|--|
| Oil layer | $RLLD \geq 15$ and $RLLD \geq 1.3 * AC + 327.5$ | |
| Oil-water layer | $2 < RLLD < 15$ and $AC > 240$ Or $1.04 * AC + 258.65 < RLLD < 1.3 * AC + 327.5$ and $AC \leq 240$ | AC—Acoustic time difference, $\mu s/m$ |
| Water layer | $RLLD \leq 12$ or $RLLD \leq 1.04 * AC + 258.65$ | |

TABLE 10: Accuracy of identification chart of Putaohua oil layer.

| Classification | Plate | Well number | Oil layer | Oil-water layer | Water layer | Total layer | Misjudge the number of layers | Correct number of layers | Accuracy |
|----------------|-----------------|-------------|-----------|-----------------|-------------|-------------|-------------------------------|--------------------------|----------|
| Zone 1 | RT- Δ SP | 16 | 20 | 13 | 2 | 35 | 2 | 33 | 94.3 |
| | RT-CNL | 15 | 16 | 13 | 0 | 29 | 0 | 29 | 100.0 |
| | RT-AC | 16 | 20 | 13 | 2 | 35 | 1 | 34 | 97.1 |
| Zone 2 | RT- Δ SP | 19 | 13 | 19 | 3 | 35 | 7 | 28 | 80.0 |
| | RT-CNL | 14 | 10 | 17 | / | 27 | 1 | 26 | 96.3 |
| | RT-AC | 17 | 11 | 16 | 3 | 30 | 6 | 24 | 80.0 |
| Zone 3 | RT-CNL | 19 | 9 | 22 | 8 | 39 | 6 | 33 | 84.6 |
| | RT-AC | 22 | 9 | 23 | 10 | 42 | 8 | 34 | 81.0 |

Combined with the oil-water logging data, oil test results and productivity in the study area, the plane oil-water distribution maps of the three sandstone formations in Putaohua oil layer are compiled (Figures 2, 3, and 4). On the whole, this research area mainly study the oil layer, water layer, oil-water same layer, and dry layer. The relationship between oil and water is relatively complex. Oil area, water area, and oil-water area alternate, and there is no obvious oil-water separation zone. However, the oil in Putaohua reservoir is mainly developed in the middle gentle slope area, steep slope area, and Longhupao structure. Other areas are scattered, which corresponds to the productivity results of each division. From the situation of each division, the northern gentle slope area is mainly oil-water same layer. The middle gentle slope area is dominated by oil layers and oil-water layers. In the steep slope area, there are not only oil layers and oil-water layers but also water layers and dry layer. The deep depression is dominated by water layer, followed by oil layer, and dry layer is sporadically developed. Longhupao struc-

tural area mainly develops oil layers, oil-water layers, and water layers are less developed, and dry layers are not developed.

2.2. Reservoir Type

2.2.1. Fine Anatomy of Oil Reservoir. In order to clearly understand the reservoir types at different structural positions in the study area, the “three horizontal and three vertical” section route covering the whole area and near parallel to the source and vertical source direction is designed to carry out the fine anatomy of the reservoir (Figure 5). Two representative oil reservoir profiles with one horizontal and one vertical profile are drawn.

The reservoir profile near the east-west direction is analyzed in this study, as shown in Figure 6,

The oil reservoir profile of well 9GL242-161-9G31 is the transverse middle section of the study area. This oil reservoir profile is located in the middle of the study area, which is

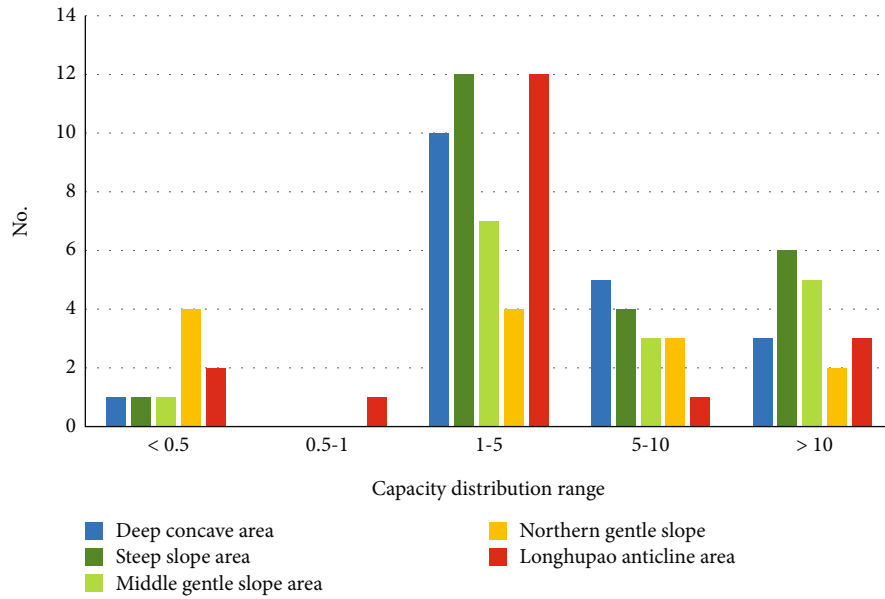


FIGURE 1: Productivity distribution of grapevine oil layer.

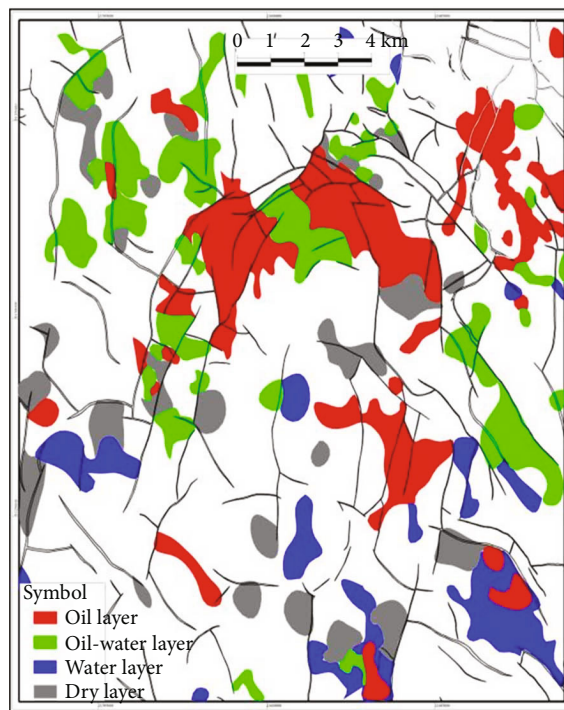


FIGURE 2: Upper of oil and water distribution on Portugal I.

mainly composed of water layers, and the oil and oil layers are less developed. The Well named “9G41” is located in Longhupao structural area, and its reservoir formation is controlled by structure, forming a structural reservoir. These Wells named “9L231-2” and 9LS2001” accumulated oil and formed a fault reservoir due to fault shielding.

The oil reservoir section near the north-south direction is researched. In Figure 7, vertical section III of the well

9L132-3-9G34 study area. This oil reservoir profile is located in the east of the study area, vertically passes through the Longhupao structural area, and is almost parallel to the northern provenance direction. Underwater distributary channel microfacies are mostly developed. On the whole, the northern and central parts are dominated by oil layers, with oil-water developed in the same layer, and the southern part is dominated by water layers, with good oil-water

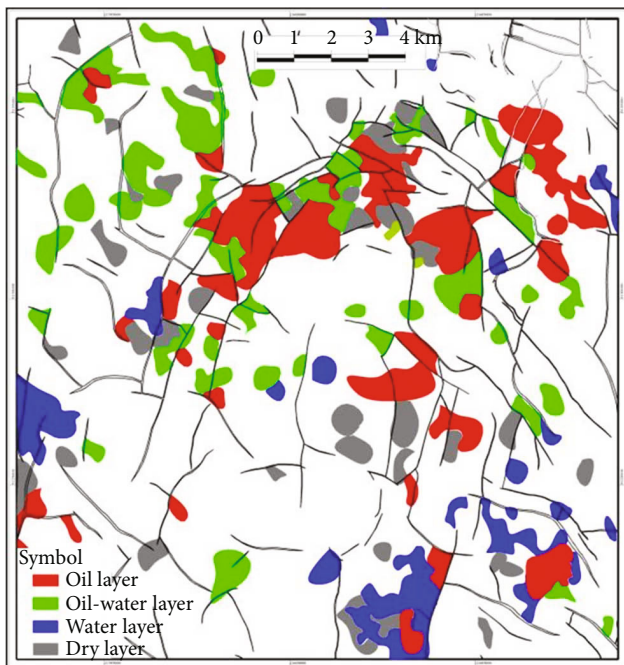


FIGURE 3: Medium of oil and water distribution in Portugal I.

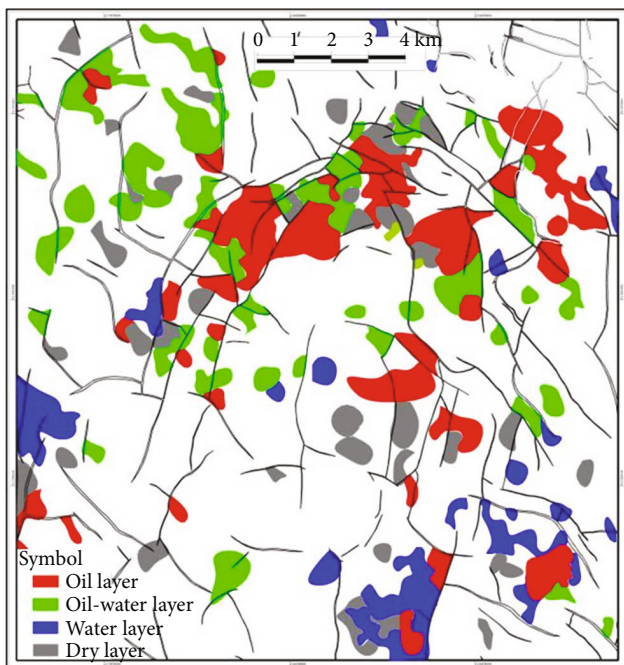


FIGURE 4: Lower of oil and water distribution in Portugal I.

differentiation. The well named “9L172” is located in Longhupao structural area, and its reservoir formation is controlled by structure, forming a structural reservoir. 9L31-2 is controlled by faults in the middle of the study area, forming a fault reservoir. The Well named “9GLB320-S482” is on the underwater distributary channel, which controlled by lithology to form a lithologic reservoir.

2.2.2. Reservoir Type and Characteristics. Through the detailed anatomy of the oil reservoirs in the study area, it is found that there are mainly three types of oil reservoirs in the study area. Longhupao structural area is dominated by structural oil and gas reservoirs. Lithologic reservoirs are developed on the underwater distributary channel. On the whole, it is dominated by fault reservoirs.

(1) Lithologic reservoir

Lithologic oil and gas reservoir: this kind of reservoir is often caused by the pinch out of upward inclined sand body, and oil and gas accumulate in sandstone to form a reservoir. This kind of reservoir in the study area is mainly developed on the underwater distributary channel, which is characterized by many oil-bearing formations and large oil-bearing areas.

(2) Fault reservoir

Fault reservoir: this kind of reservoir is formed under the control of faults. The reservoirs in the study area are mainly fault reservoirs, which are mainly distributed in the middle of the study area.

(3) Structural reservoir

Structural reservoir: this kind of reservoir is mainly an oil and gas reservoir under the control of anticline structure. This type of reservoir in the study area is mainly distributed near the Longhupao structure.

Through the study of oil and gas distribution law and reservoir types in long12 area, comprehensively speaking, there will be pure oil layer or pure water layer in some areas, and there will also be oil-water inversion, which shows that the oil-water relationship in the study area is relatively complex, and there are three types of reservoirs: fault reservoir, structural reservoir, and lithologic reservoir.

3. Results

Based on the study of oil-water distribution law and the anatomy of typical reservoirs, the oil-gas accumulation conditions such as source rocks, reservoirs, caprocks, traps, and migration are analyzed. Combined with the study of oil-water distribution characteristics, it is found that the formation of Putaohua oil reservoir in long12 block of DaqingLonghupao oilfield is mainly affected by two factors: the dominant migration path controls the distribution of oil and the effective traps on the dominant migration path controls the favorable accumulation position of oil.

3.1. Dominant Migration Path Controls Oil Distribution. In terms of the previous fine structure interpretation results, four types of faults are developed vertically in the study area. According to the migration conditions, the first and second types of faults are the oil source faults in the study area, which are the dominant channels for oil and gas migration in the vertical direction, and the third and fourth types of faults are the internal segmentation faults of Putaohua oil



FIGURE 5: “Three horizontal and three vertical” typical reservoir profile.

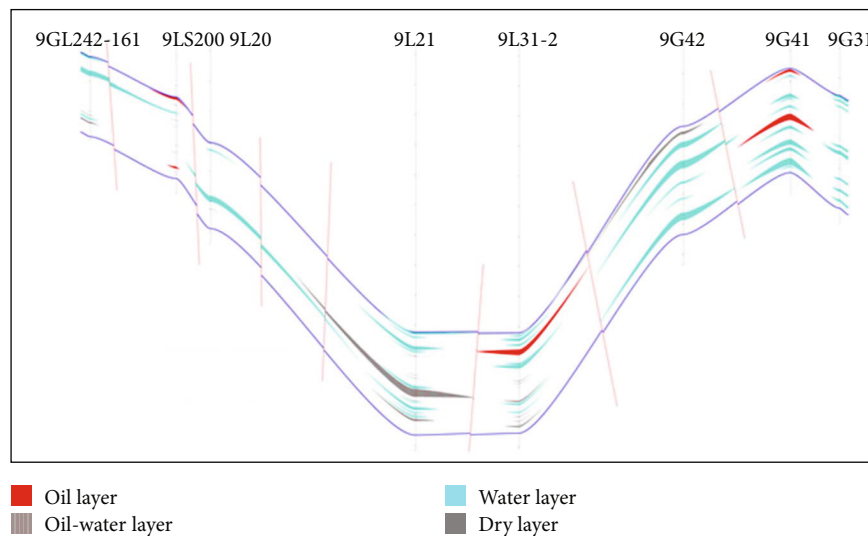


FIGURE 6: 9GL242-161—9G31well reservoir profile.

layer in the study area. Among them, 71 oil source faults of class I and class II are developed in the study area, mainly distributed in the central gentle slope area, steep slope area, and Longhupao structural area.

According to the oil-water horizontal distribution characteristics and oil-water productivity distribution previously studied, the oil layers are mainly distributed in the central gentle slope area, steep slope area, and Longhupao structural area, and the productivity is also the highest in these three areas, which is consistent with the main distribution areas of oil source faults. The oil source faults in the whole region are compared with 92 oil testing and production wells in the Putaohua oil layer. It is found that there are 55 reservoirs related to oil source faults, accounting for 60% (Table 11), indicating that the closer the wells are to the oil source faults in the study area, the better the effect of oil testing and production is; superimposing the oil source faults with the oil-bearing area map, it is found that the oil-bearing area in the oil source fault intensive area is larger.

Based on the discussion, it shows that oil source faults control the enrichment degree of oil and gas accumulation.

3.1.1. Palestructures and Dominant Facies Zones Control the Migration and Accumulation Trend of Oil. From the early structural evolution history, it can be seen that the paleostructure plays an important role in controlling the migration direction of oil. Therefore, the paleostructure recovery and fluid potential characteristics of Putaohua oil layer during the reservoir forming period are studied. The results show that the migration trend of oil in Putaohua oil layer during the reservoir forming period is on both sides of the syncline central axis and the anticline structural axis. Combined with the analysis of the dominant reservoir facies, ten lateral dominant migration channels are developed.

Because the migration trend and lateral migration path of oil during the accumulation period of Putaohua oil layer mainly control the distribution of oil and water, the oil-bearing area map is superimposed with the migration trend

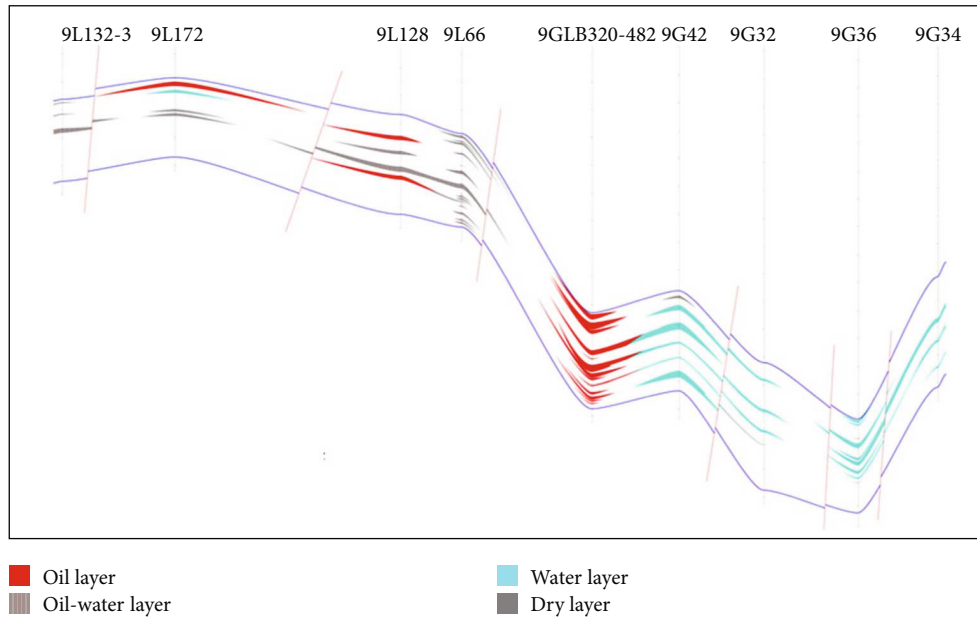


FIGURE 7: Well named “9L132-3—9G34” reservoir profile.

TABLE 11: Relationship between reservoir and fracture.

| Relationship between reservoir and fracture | Large fault type | Number of oil wells tested and produced | Number percentage (%) |
|---|------------------|---|-----------------------|
| Relevant | Class I fault | 20 | 22 |
| | Class II fault | 35 | 38 |
| | Class III fault | 13 | 14 |
| Not relevant | Class IV fault | 24 | 26 |

and lateral dominant migration path, and then the analysis shows that the oil-bearing area is basically distributed on both sides of the dominant migration path controlled by the dominant facies belt and the migration trend controlled by the pale structure. Based on the above discussion, it shows that the pale structure and dominant reservoir facies belt control the trend of oil migration and accumulation.

Based on the superposition analysis of the migration trend controlled by oil source faults and pale structures and the migration path controlled by dominant facies zones, the oil-bearing area is basically distributed around the migration trend controlled by oil source faults and pale structures and the migration path controlled by dominant facies zones. In conclusion, the dominant migration path of oil controls the distribution of oil.

3.2. *Effective Traps on the Dominant Migration Path Control the Favorable Accumulation Position of Oil.* According to the previous research results, the sealing of the fault in the study

area is calculated according to the SGR principle. On this basis, combined with the top structural map of Putaohua oil layer, the types and distribution characteristics of trap development are analyzed. Through the superposition of the above lateral dominant migration path and trap, well TA 35 block and well TA 3501 block on the dominant migration path are selected for analysis to determine whether oil can accumulate and form reservoirs.

(1) Block analysis of well Ta 35

The vicinity of well Ta 35 is clamped by three faults lyxF12, lyxF2, and dlf9. TrapTester software is used to model the structure of the three faults and calculate the SGR value of the section. The SGR of the three reservoir control faults is greater than 20%, which belongs to a strong closed fault and forms an effective trap. The oil test results show that wells Ta 35 and Ta 35-2 controlled by lyxF2, lyxF12, and dlf9 faults are industrial oil flow wells in Putaohua oil layer (Table 12).

Through the analysis of this result, it can be seen that effective traps on the dominant migration path can make oil accumulate.

(2) Block analysis of well Taxie 3501

The updip direction of Tashi 3501 is clamped by two faults wyF13 and lyxF12. TrapTester software is used to model the structure of two reservoir controlling faults and calculate the SGR value of the section. The SGR value of wyF13 section is 18%, which belongs to a weakly closed fault and does not form an effective trap. The oil test results show that (Table 13), the oil test results of well Taxie 3501 on PI are water layers.

Through the analysis of this result, we can see that wy13 is a weak closed fault, and the failure of forming an effective

TABLE 12: Statistics of SGR value of wells around Ta 35 well and reservoir control fault section.

| Well | Formation | Depth/m | Well testing type | Well testing result | Control ring fracture | SGR/% |
|--------|-----------|---------------|--------------------------|----------------------|-----------------------|-------|
| Ta35 | PI upper | 1676.0-1690.6 | MFEII+flow automatically | Commercial oil layer | lyxF12 | 25-27 |
| Ta35-2 | PI upper | 1690.4-1694.2 | Post pressure swabbing | Commercial oil layer | lyxF12 | 25-27 |

TABLE 13: Statistical table of production test results and SGR value of reservoir control fault section of well Taxie 3501.

| Well | Formation | Perforation depth/m | Well testing type | Well testing result | SGR-lyxF12 | SGR-wyF13 |
|-----------|-----------|---------------------|------------------------|---------------------|------------|-----------|
| Taxie3501 | PI upper | 1695.4-1697.4 | Post pressure swabbing | Water layer | 27% | 18% |

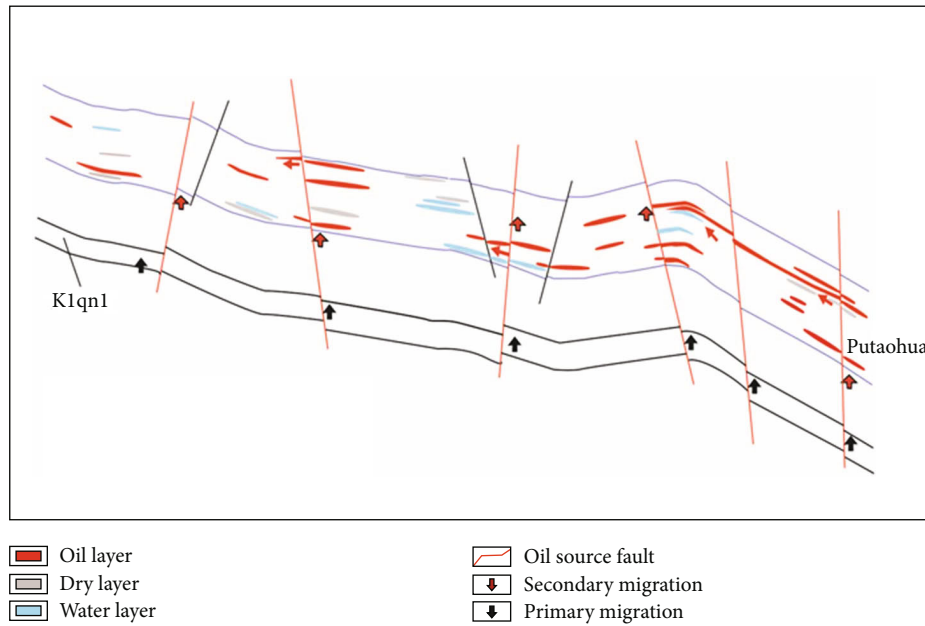


FIGURE 8: Reservoir forming mode diagram of Putaohua oil layer.

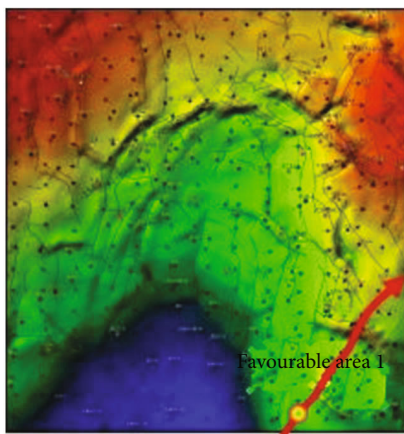


FIGURE 9: Favorable area 1 migration trend controlled by paleostructure.

trap is the main reason for the failure of this well, which further explains that the effective trap on the dominant migration path controls the favorable accumulation position of oil.

4. Discussion

4.1. Hydrocarbon Accumulation Model. Oil and gas accumulation is a dynamic process. After hydrocarbon generation in source rocks, oil and gas migrate until they enter effective traps and converge to form reservoirs.

The research results of source rock conditions show that long12 block is located in the hydrocarbon expulsion distribution area. Therefore, after oil generation, the source rock of the Qing1 member migrates upward by relying on the oil source fault under the action of buoyancy and overpressure and reaches the target Putaohua oil layer. Under the migration trend controlled by paleotectonics, it migrates laterally through the sand body controlled by the dominant reservoir facies belt, and finally, enters the effective trap to accumulate and form reservoirs (Figure 8).

4.2. Prediction of Favorable Areas. According to the main controlling factors of reservoir formation in the study area, combined with the characteristics of oil-water distribution, the favorable target area for oil and gas accumulation in

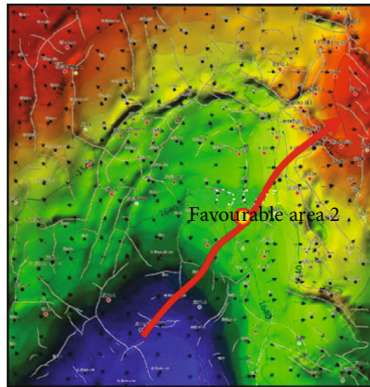


FIGURE 10: Favourable area 2 migration trend controlled by pale structure.

the Putaohua oil layer in long12 block of Longhupao oilfield is predicted, and the prediction criteria are as follows:

- (1) There is no well in the favorable block
- (2) Located near the oil source fracture
- (3) It is located on or near the migration trend controlled by paleo structure and the dominant migration path controlled by dominant facies belt
- (4) Located in the effective trap

According to the principles, two favorable areas are finally selected for Putaohua oil layer in the study area. Favorable area 1: north of long128 well, there is no well in the area; Favorable area 2: there is no well in the south of long 10 well.

In the favorable area 1, in the west of well Gu 30, there is no well in the area, which is located next to the migration trend controlled by paleotectonics. The underwater distributary channel of the dominant reservoir facies belt is developed and located on the dominant sand body channel. The surrounding oil source faults are developed. As shown in Figure 9, the upper shielding fault has strong sealing property, located in the effective trap, the reservoir prediction results of seismic inversion show that the sandstone in this block is developed, and the predicted sandstone thickness is 11.9 m.

In the favorable area 2, there isn't exist well in the south of long 10 well, located on the dominant migration trend controlled by paleotectonics. The underwater distributary channel of the dominant reservoir facies belt is developed and located on the dominant sand body channel. The surrounding oil source faults are developed. The upper shielding fault has strong sealing property and is located in the effective trap (Figure 10); the reservoir prediction results of seismic inversion shows that the sandstone in this block is developed, and the predicted sandstone thickness is 14.5 m.

5. Conclusions

- (1) The main source rock of the long12 block in Longhupao oilfield is the first member of the Qingshan-kou formation. The thickness of mudstone is 53-79 m, and the average TOC content is 2.01%. The type of organic matter is mainly type III kerogen. The degree of thermal evolution is in the mature stage, and they are all in the hydrocarbon expulsion distribution area, which has good source rock conditions
- (2) The lithology of Putaohua oil layer in long12 block of Longhupao oilfield is mainly siltstone, which belongs to medium low porosity and medium low permeability reservoir. The sedimentary facies type is delta inner front facies, and the oil content of underwater distributary channel sand body is the best, followed by the main sheet sand, and the nonmain sheet sand is the worst; it has good sealing caprock. Fault traps are mainly developed, structural traps are developed in Longhupao structural area, and lithologic traps are less developed
- (3) There are four types of faults in long12 block of Longhupao oilfield. The first and second types of faults are oil source faults, which are the dominant channels of vertical migration. The third and fourth types of faults are internal segmentation faults of Putaohua oil layer
- (4) The oil-water distribution of Putaohua oil layer in long12 block of Longhupao oilfield is complex vertically, including both upper oil and lower water and upper and lower water oil. The oil layers on the plane are mainly developed in the gentle slope area, steep slope area and Longhupao structural area in the middle of the study area, and scattered in other areas

Data Availability

All data included in this study are available upon request by contact with the corresponding author.

Conflicts of Interest

The authors declare no conflict of interest.

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References

- [1] L. Xiuxiang, "Experimental study on oil migration loss of unconformity in Tarim Basin," *Journal of University of petroleum: Natural Science Edition*, vol. 24, no. 4, p. 3, 2000.

- [2] A. Aydin, "Fractures, faults, and hydrocarbon entrapment, migration and flow," *Marine & Petroleum Geology*, vol. 17, no. 7, pp. 797–814, 2000.
- [3] A. Jeffrey and Nunn, "Kilometer-scale upward migration of hydrocarbons in Geopressed sediments by buoyancy-driven propagation of methane-filled fractures," *AAPG Bulletin*, vol. 86, no. 5, pp. 907–918, 2002.
- [4] F. Nie, S. Li, and W. Hua, "Lateral migration pathways of petroleum in the Zhu III subbasin, Pearl River Mouth basin, South China Sea," *Marine & Petroleum Geology*, vol. 18, no. 5, pp. 561–575, 2001.
- [5] X. Caifu, X. Bin, and X. X. Nong, "The main transportation channel of oil and gas migration in the western slope of Songliao Basin," *Petroleum and natural gas geology*, vol. 25, no. 2, pp. 204–208, 2004.
- [6] Y. K. Kharaka, "Petroleum formation and occurrence. A new approach to oil and gas exploration," *Earth Science Reviews*, vol. 16, no. 16, pp. 372–373, 1978.
- [7] J. Fujie, Y. Haijun, and W. Shen, "Ordovician carbonate oil and gas transportation framework and its reservoir control model in Tazhong area," *Journal of Petroleum*, vol. S2, p. 9, 2015.
- [8] L. Xiaorong, Z. Liguan, and L. Qianjin, "Simulation and analysis of the mechanical process of oil and gas migration in Shahejie formation of Chengbei fault terrace belt," *Petroleum and Natural Gas Geology*, vol. 28, no. 2, pp. 191–197, 2007.
- [9] Y. Deng, *Transfer Station Model of Oil-Gas Migration Formed by Fault-Sandbody*, vol. 23, China Petroleum Exploration, 2005.
- [10] Y. Y. Liu, "Oil and gas migration transporting pathways of Ed1 and their controlling to oil and gas accumulation in Nanpu depression," *Science Technology and Engineering*, vol. 42, pp. 36–39, 2013.
- [11] X. Zeng, H. Zhang, and J. Zhao, *Lithology of Guantao Formation in the Eastern Bohai Sea and its bearing on oil and gas accumulation*, vol. 97, Marine Geology Frontiers, 2017.
- [12] S. Henares, L. Caracciolo, G. Cultrone, J. Fernández, and C. Viseras, "The role of diagenesis and depositional facies on pore system evolution in a Triassic outcrop analogue (SE Spain)," *Marine & Petroleum Geology*, vol. 51, pp. 136–151, 2014.
- [13] Y. You, X. Niu, and S. Feng, "Study on micro pore characteristics of Chang 7 tight oil reservoir in Yanchang, Ordos Basin," *Journal of China University of petroleum: Natural Science Edition*, vol. 38, no. 6, p. 6, 2014.
- [14] H. Chaoyuan, "Oil generating areas control the distribution of oil and gas fields – an effective theory for regional exploration in continental basins in eastern China," *Journal of Petroleum*, vol. 2, pp. 13–17, 1982.
- [15] H. Chaoyuan, "Discussion on regional control factors of oil and gas field distribution in offshore sedimentary basins in China," *Marine Geology and Quaternary Geology*, vol. 4, pp. 25–31, 1986.
- [16] H. Chaoyuan, "Research on the appliance extent of "source control theory" by semi-quantitative statistics of oil and gas migration distance," *Natural Gas Industry*, vol. 25, no. 10, pp. 1–3, 2005.
- [17] X. Tong and J. Niu, "The role of regional cap rocks in oil and gas accumulation," *Petroleum Exploration and Development*, vol. 2, pp. 76–79, 1989.
- [18] L. Yi, *Fault-source-reservoir-cap combinations and their control on accumulation in foreland thrust belt of Kuqa depression*, China Petroleum Exploration, 2013.
- [19] W. H. Xjjpg and X. Zhou, *Source-cap co-control theory and its application to hydrocarbon prospecting in Tarim Basin*, Xinjiang Petroleum Geology, 2000.
- [20] D. Guo, *Reservoir controlling action of the spatial matching between the oil source fault and other accumulating factors*, Petroleum Geology & Oilfield Development in Daqing, 2017.
- [21] Q. Luo, Z. Jiang, and X. Pang, *Mechanism and mode of fault reservoir control*, Petroleum Industry Press, 2007.
- [22] X. Zhou, C. Niu, and C. Teng, "The relationship between fault activity and hydrocarbon accumulation during neotectonic movement in the Central Bohai Sea area," *Petroleum and natural gas geology*, vol. 30, no. 4, p. 8, 2009.
- [23] M. Li, X. Yue, and Q. Jiang, "Types of fault depression transportation system and its reservoir control in the central Hailar-Tamtsag Basin," *Petroleum and natural gas geology*, vol. 33, no. 3, p. 11, 2012.
- [24] Q. Luo, Z. Jiang, and X. Pang, *Mechanism and mode of fault reservoir control [M]*, Petroleum Industry Press, 2007.
- [25] L. Hao, Y. Jiang, and H. Xu, *Relationship between fault activity period and Neogene oil-gas accumulation in Raoyang sag*, Fault-Block Oil & Gas Field, 2011.
- [26] Y. H. Sun, L. Kang, and F. X. Yang, "Analysis of fault characteristics and reservoir forming control in middle fault depression belt in Hailer-Tamtsag Basin," *Advanced Materials Research*, vol. 616–618, pp. 174–184, 2012.
- [27] L. Chang, D. Chen, and Y. Dong, "Control of faults on hydrocarbon accumulation of buried hill reservoirs in the Nanpu sag, Bohai Bay basin," *Oil & Gas Geology*, vol. 36, no. 1, pp. 43–50, 2015.
- [28] C. L. Hearn, W. Ebanks, R. S. Tye, and V. Ranganathan, "Geological factors influencing reservoir performance of the Hartzog draw field, Wyoming," *Journal of Petroleum Technology*, vol. 36, no. 8, pp. 1335–1344, 1984.
- [29] Y. Jiang, H. Liu, and G. Song, "Differential hydrocarbon enrichment and its Main controlling factors in depressions of the Bohai Bay basin differential hydrocarbon enrichment and its Main controlling factors in depressions of the Bohai Bay basin," *Acta Geologica Sinica - English Edition*, vol. 73, pp. 88–92, 2017.