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Research Article

Optimal Selection Method for Sweet Spots in Low-Permeability Multilayered Reservoirs

Xiangwu Bai,[1,2] Zhiping Li ,[1,2] and Fengpeng Lai [1,3]

[1] *School of Energy Resources, China University of Geosciences, Beijing 100083, China*
[2] *Beijing Key Laboratory of Unconventional Natural Gas Geological Evaluation and Development Engineering, Beijing 100083, China*
[3] *State Key Laboratory of Shale Oil and Gas Enrichment Mechanisms and Effective Development, Beijing 100083, China*

Correspondence should be addressed to Zhiping Li; lzp_cugb@163.com

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Low-permeability oil reservoirs account for more than two-thirds of China's proven reserves, and most of them are multilayered; the traditional sweet spots focus on single-layered reservoirs. The sweet spots of low-permeability reservoirs have two meanings: the geologically superior reservoir and the beneficial development of the reservoir. In this study, a concept of reservoir stratification coefficient is proposed to evaluate the characteristics of multilayered reservoirs, and three indicators are proposed, namely, reservoir stratification coefficient, energy storage coefficient, and stratigraphic coefficient, as the indicators of sweet spots of multilayered reservoirs. The three indicators are combined into a single indicator using a weighted approach, and the sweet spots can be identified based on the combined indicator. The Xiliu A area of the North China oilfield was selected for a case study. According to the structural, sedimentary, and reservoir characteristics of the block, combined with the development and production conditions, the Sha 3 Member I oil group was selected as the study object of sweet spots of the low-permeability reservoir. The results show that the reservoir stratification coefficient, energy storage coefficient, and stratigraphic coefficient proposed in this study are effective indicators for the preferential selection of sweet spots, which can reflect the longitudinal heterogeneity, energy storage size, and flow capacity of multilayered reservoirs. After a comparative analysis with actual blocks, it was found that the results obtained using the method are consistent with the actual capacity of the reservoir. The production capacity is high. The evaluation effect is ideal, and the applicability is good. Thus, this study provides a new technical method for the evaluation of similar multilayered reservoirs. The findings of this study can help for a better understanding of the development and production conditions and optimization basis of low-permeability reservoirs.

1. Introduction

Low-permeability multilayered oil reservoirs in China are characterized by dense lithology, fine pores and throats, poor physical properties, and the development of natural fractures and strong heterogeneous structures. In addition, these types of reservoirs are longitudinally multilayered and thin with differences in lithology and physical properties among the small layers, thus making it difficult for a single small layer to be productive. This leads to the interaction of geological factors between various strata, reflecting the uneven degree of utilization both horizontally and vertically [1, 2]. Therefore, with the increase in oilfield exploration and development work, the optimal classification and evaluation of reservoir sweet spots have received more and more attention. This is important for improving the development effect and level of development and achieving scientific management of oilfields [3, 4].

At present, preferential selection of sweet spots of low-permeability oil reservoirs has been extensively studied. Different weight parameters have been selected to evaluate the sweet spots of reservoirs. Some scholars reported that the main roar radius, starting pressure gradient, and clay content and type play an important role in the preferred system, and two parameters, movable fluid saturation and crude oil viscosity, also play an important role; some of them considered several parameters such as reservoir sedimentary phase, sand thickness, physical characteristics, orifice throat characteristics, discharge pressure, and thus classified preferences [5–9]. Other scholars optimized the reservoir sweet spots by using lithology, porosity, permeability, effective thickness, median radius, discharge pressure, and sorting coefficient as evaluation indexes [10]. Although previous studies obtained some results, there are still some shortcomings, mainly because these sweet spot parameters do not consider the multilayer specificity of hypotonic multioil reservoirs, making the reservoir sweet spot preferences not achieve the expected results. Despite the richness of the current reservoir sweet spots, the results are different because each method considers the problem from a different perspective and has a different approach to solve the problem, plus the differences in the objects used [11–14]. In particular, no recognized and valid evaluation indicators were found for the preference of parameters.

In this study, with respect to the characteristics of low-permeability and multioil reservoirs of the 3rd member of the Shahejie Formation I oil group in the Xiliu A (XA) block, select the best among many evaluation indicators and methods. Therefore, "effective reservoir thickness, number of reservoir layers, effective porosity, permeability, and oil saturation" were preferentially selected as the five categorical evaluation parameters with reference to reservoir permeability. Unlike the previous case where only the evaluation parameters were considered, based on different combinations of the five key parameters for reservoir evaluation, three indicators were preferentially selected. The three indicators were combined into one indicator using a weighting method. Based on this composite indicator, the sweet spot region was eventually identified (Figure 1). The innovation of this study lies in the development and quality evaluation and comparison of the benefits of the "sweet spot" of low-permeability multilayered reservoirs, which provides a reference for the selection of target areas for economic exploitation.

Overall, this paper can be divided into four sections. First, the geologic aspects are presented in Section 2. Then, Section 3 describes the optimization of reservoir sweet spot parameters and indicators. Furthermore, Section 4 describes the optimization of the reservoir sweet spot method. Finally, Section 5 describes the application of this method to study a case.

2. Geologic Aspects

2.1. Structural Feature. The structure of the XA block is a monoclinal fault block, mainly controlled by XA, XA west, and Gao B (GB) faults. The extension of the XA fault is 8.2 km, and the extension of the GB fault is 6.7 km. The stratum in the fault block dips to the southeast, and the dip angle of the stratum is between 8° and 12°. The depth of the sand stratum in the Sha 3 Member of the fault block is 2820 m. The amplitude of closure is 220 m, and the area of closure is 8.55 km^2. The formation of XA fault tectonics is mainly caused by the occlusion of a reverse positive fault present in the northern part of the fault (Figure 2). Owing to its formation in the upward-dipping direction of the structure, tectonic inheritance is particularly prominent in the upper and lower strata. In the entire block, there is only one minor secondary fault that warps the stratigraphic pattern to the north. It is inclined in the east, west, and south directions. In summary, it is considered that the overall structure of the XA fracture remains relatively intact.

2.2. Lithological Feature. The lithology of the XA block reservoir is mainly light gray fine sandstone. Currently, three coring wells are present on the block: GC, XD, and XE wells. After the analysis of their core data, it is concluded that the lithology of the XA block is mainly a clastic felsic fine sandstone, with a large proportion of quartz content in the clasts. Quartz content is 46-56%. Feldspar content is the next, 27-32%, while the rock chip content is only 14-21%. The main component of rock chip composition is made of acidic, medium-basic ejecta rock chips, and the rest is mainly made of sedimentary rock chips. The degree of particle weathering is moderate with a predominantly subridge-subround shape, and the degree of sorting is in a moderate-to-good state, making the pattern of point-line contact particularly prominent between particles. The block has two main forms of pores, namely, intersolution pores and intergrain pores, with pore diameters ranging from 0.01 mm to 0.05 mm. Therefore, it is considered that the pore development in the XA block fracture is average.

2.3. Sedimentary Feature. The sedimentary environment of the Sha 3 Member of the XA block is dominated by a deltaic plain, forming a transition zone between the front of the braided river deltaic plain and its front edge. The Sha 3 Member of the feed system controls the formation of a reservoir in this section, the most potential member in the study field. In particular, the Sha 3 Member I oil group is divided into small layers of four sand groups. The analysis shows that the oil reservoirs in the Sha 3 Member of the XA block are mainly distributed in the phase change area of diversion channels, where the 2nd and 3rd small layers of the sand body with better connectivity are mainly diversion channels with more development in the plane. Those with overall poor connectivity in the plane are the 1st and 4th minor layers, mostly developed as diverging interchannel bays (Figure 3).

2.4. Reservoir Characteristics. The XA block has three pay zones, namely, Sha 1 Member, Sha 2 Member, and Sha 3 Member, with an oil-bearing well length of about 180 m. Among them, the Sha 3 Member accounts for 66.1% of the total thickness, and it is the main oil-bearing reservoir system. The geological reserve of the Sha 3 Member is 615.58 $\times 10^4$ t, as obtained by volumetric calculation. The oil saturation is 57.9%, and the effective thickness is 6.2 m, as obtained using the contour area trade-off method. The physical properties of the whole reservoir in the XA block are poor, with effective porosity of 17.7% and permeability of 16.9×10^{-3} μm^2 in the eastern part of the block, a medium-low-porosity hypotonic oil reservoir. The physical properties of the western reservoir are significantly inferior to those of the eastern part of the block, with effective porosity of 14.9% and permeability of 8.7×10^{-3} μm^2, a medium-low-porosity ultra-low-permeability oil reservoir (Table 1). The XA block has been evaluated; for example, some scholars used single parameters such as sandstone grain size, reservoir physical properties,

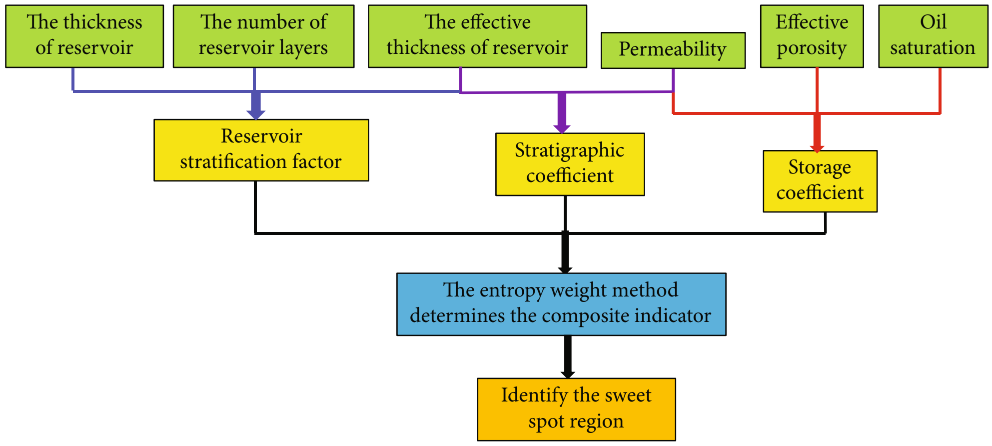

Figure 1: The sketch of the identification sweet spot region process in low-permeability reservoirs.

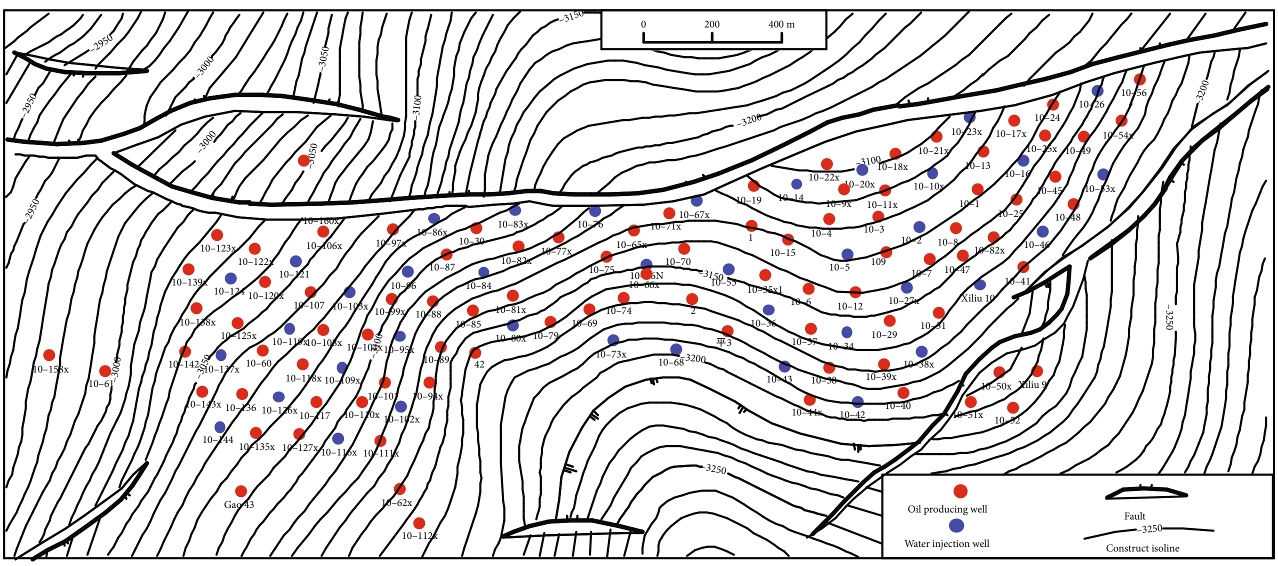

Figure 2: Structural map of the top surface of the Es_3 oil formation in the XA block.

and reservoir micropore structure to classify and evaluate the Shahejie Formation reservoir in the XA block [15]. The reservoir in this area was classified into four categories, Class I (rich), Class II (moderate), Class III (poor), and Class IV (very poor).

2.5. Development Status. So far, a total of 163 oil and water wells are present in the XA block: 115 of them are producing wells, and 48 of them are injection wells with a well network density of 7.2 wells/km^2. By December 2019, 44 injection wells were open with a daily injection of 975.29 m^3 and a cumulative total of 409.03×10^4 m^3 of water, and 110 oil production wells were open with a verified daily production of 1025 t of fluid. The daily oil production was 240.2 t. The combined water content was 76.57%. The cumulative oil production was 150.12×10^4 t. The recovery rate was 0.57. The recovery degree was 9.74%, and the nominal recovery rate was 22.27%.

3. Optimization of Reservoir Sweet Spot Parameters and Indicators

3.1. Optimal Reservoir Parameters. A principle of selecting the parameters of reservoir sweet spots was established. The parameters should be representative, integral, and relatively independent from one another, and they should be consistent with the actual geological characteristics to ensure the reliability of the data source. Thus, five categorical evaluation parameters were used as a reference for reservoir storage and percolation capability, and the selected parameters are effective reservoir thickness, number of reservoir layers, effective porosity, permeability, and oil saturation.

(1) The effective thickness of the reservoir (h) is an important parameter for reservoir evaluation and reserve calculation. This is the thickness of that part of the reservoir with industrial oil production capacity. When delineating the effective thickness of reservoir layers, it

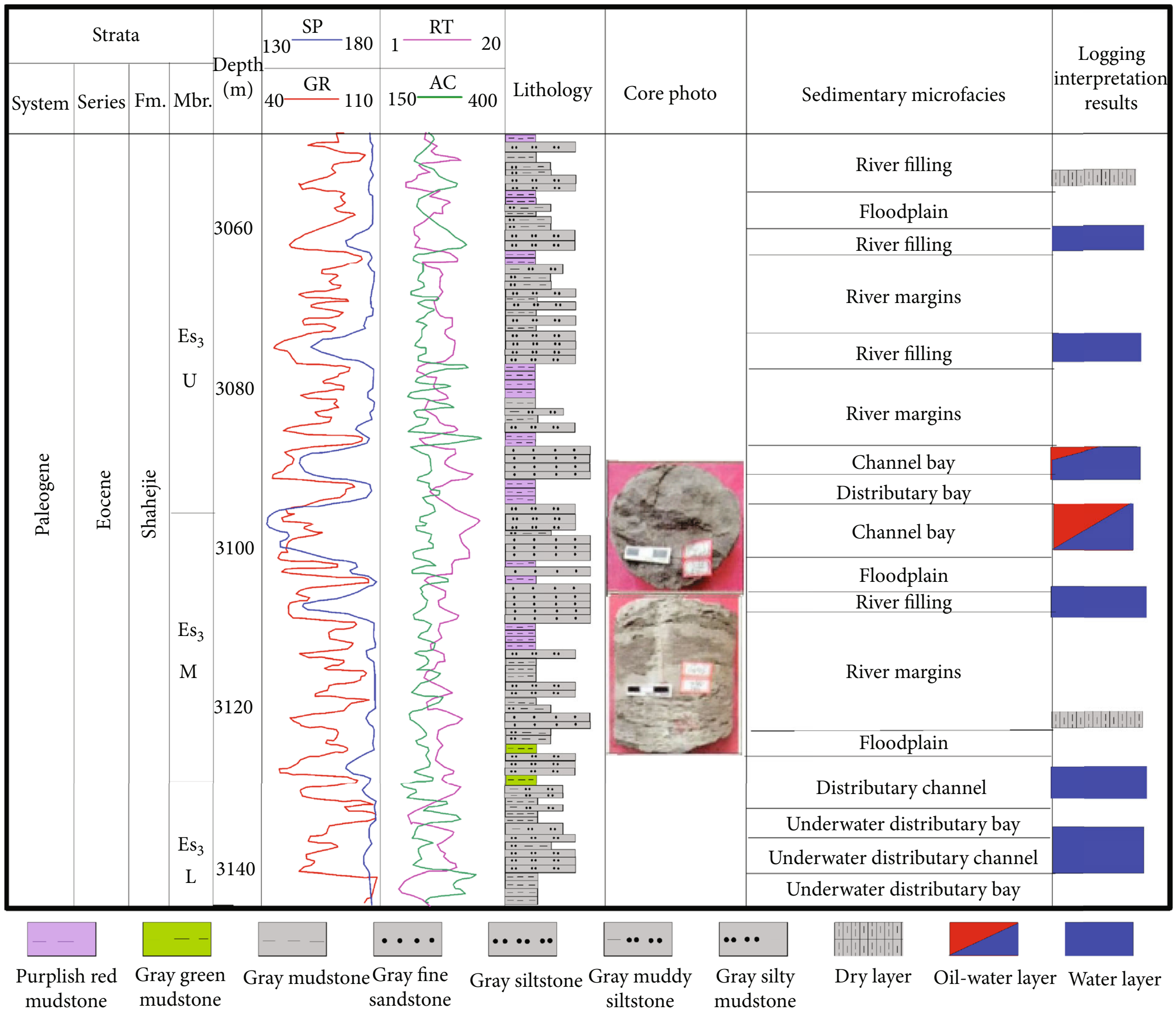

Figure 3: Composite column of the 3rd members of the Palaeogene Shahejie Formation in the XA block.

Table 1: Core analysis data statistics of Es_3 in the XA fault.

Well area	Well name	Well interval (m)	Horizon	Porosity (%)	Effective permeability ($10^{-3}\mu m^2$)
Eastern well area	Xiliu 109	3128.70-31454.80	Es_3	17.7	16.9
	Statistics of porosity and permeability data in the eastern well area			17.7	16.9
Western well area	Xiliu 10-142	3025.95-3042.03	Es_3	14.7	6.2
	Xiliu 10-117	3095.80-3112.00	Es_3	15.9	7.7
	Gao 43	3092.55-3100.38	Es_3	14.2	12.2
	Statistics of porosity and permeability data in the western well area			14.9	8.7
Statistical average of porosity and permeability data in the XA fault				15.6	10.7

is necessary to combine the lower physical and electrical criteria of the effective thickness of reservoir layers. The parameters of the lower limit of the effective thickness should be determined comprehensively [16]

The physical lower limit of the effective thickness of the reservoir is the minimum porosity and permeability at which the reservoir can produce industrial hydrocarbons. The core, oil test, and well log data were considered together. The lower limits for the effective thickness physical properties of the reservoir in the Sha 3 Member I oil group of the XA block were determined as follows: average effective porosity of 15.6% and average air permeability of $10.7 \times 10^{-3}\ \mu m^2$. The lower limit of the reservoir effective thickness electrical

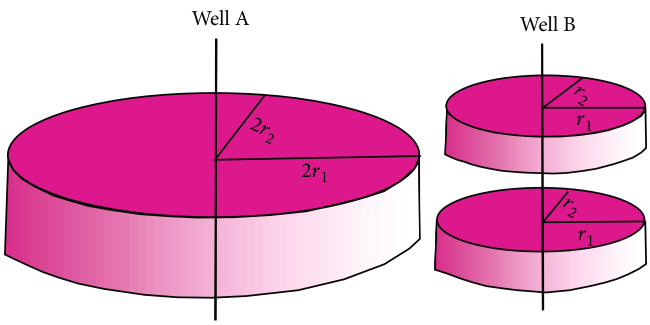

FIGURE 4: Model of reservoir distribution effects on reserves.

criterion was mainly determined from the logging data. Among the many logging curves, the deep lateral apparent resistivity, sensitive lithology density, and acoustic time difference curves can better identify the oil content of the reservoir. Those are selected as the parameter curves to study the electrical properties of the effective thickness of the reservoir. The lower limits of the effective thickness electrical criteria were confirmed as follows: an oil-bearing sandstone layer compensation density of 2.38 g/cm^3, a deep lateral apparent resistivity of 14 Ω·m, and an acoustic time difference of 250 μs/m.

Considering the relationship between effective thickness (H) and reservoir abundance as determined in reservoir reserve calculations, when the two are not that different from each other, the style of reservoir distribution will be different, and the cumulative oil production will vary considerably from well to well. The effective reservoir is presented underground as a three-dimensional geological body with a certain aspect ratio and width-to-thickness ratio [17, 18]. If the thickness of a single layer is larger, the continuity and connectivity between the reservoirs may be better, and the corresponding extensional scale of the reservoir, represented as a high-quality reservoir in the plane, may be larger. If the thickness of a certain thin sand body is h, then a thin sand body volume ($\pi r_1 r_2 h$) exists that is one-eighth the volume of a thick sand body ($8\pi r_1 r_2 h$) (Figure 4). If we drilled two wells, one well (well A) with one thick formation and the other well (well B) with two thin formations (Figure 4), and the effective thickness of each well is cumulatively 2 h, then the extension of the reservoir controlled by well B is one-fourth of that by well A. Therefore, reservoirs with monosand bodies greater than 4 m in the block are designated as thick sand bodies, while effective monosand bodies less than 4 m are prevalent in about 80% of the block. This makes the average thickness of a thick sand body (5.58 m) 2.27 times thicker than the average thickness of a thin sand body (2.46 m). Then, a case exists where the thickness is cumulatively the same, and the extension area of a thick sand body on the plane is about 5.2 times that of a thin sand body [19].

(2) The number of reservoir layers (n) refers to the number of oil sand layers in a formation. In this study, the completeness and reliability of information are used as the first consideration in determining the number of effective thickness layers of the reservoir, but for those sections with the core effective thickness, the core effective thickness is preferred. There is also a case where the core effective thickness of the interval does not exist, and the logging effective thickness is used as a choice. However, in the actual selection of the number of effective thickness layers of the reservoir, phase transitions occur in the plane, resulting in unconnected oil sand layers within the same layer. Therefore, the number of reservoir oil sand layers encountered in a single well drilling is used in this study to represent them

(3) Effective porosity (ϕ) is generally obtained by testing the core in the laboratory using the standard reservoir physical property. Effective porosity is usually defined as the volume of connected pores in the rock as a percentage of the total volume of the rock. This is considered an important indicator for the evaluation of oil and gas reservoirs. In general, the relationship between porosity ϕ and acoustic time difference Δt is considered linear; there is some variation in porosity from reservoir to reservoir, also contributing to the heterogeneity between the layers to some extent

(4) Oil saturation (S_o) is an important parameter used to calculate the geological reserve of an oil reservoir. It not only characterizes the oil content of the reservoir but also reflects the oil grade of the reservoir under different lithology and physical properties. It is generally accepted that the higher the oil-bearing grade, the better the physical properties, and the coarser the lithological grains

(5) Permeability (k) is generally considered to be its ability to allow fluids to pass through a reservoir at a given differential pressure. It is considered to be one of the parameters with the most comprehensive nature in terms of reservoir physical property. It is not only used as an important parameter when evaluating reservoir properties but also, to some extent, used as an important parameter for evaluating production capacity. Hence, when the permeability contrast between reservoirs is strong, it also indicates interlayer heterogeneity between the reservoirs, and if it exceeds three times, it may cause interlayer interference between the reservoirs

3.2. Optimization of Reservoir Sweet Spot Indicators. Unlike the previous evaluation parameters only, based on different combinations of the five key parameters of reservoir evaluation that were selected preferably, three sweet spot evaluation indicators for low-permeability multioil reservoirs, reservoir stratification coefficient, energy storage coefficient, and stratigraphic coefficient, are proposed. It avoids the inability of a single factor within the same reservoir to characterize the reservoir's oil storage capacity and can effectively guide production.

(1) The reservoir stratification factor ($h/H * n$) is the ratio of the effective sand thickness coefficient (h/H) of a well-drilled reservoir to encounter a reservoir

within a reservoir to the number of layers (n) of oil sands within that reservoir drilled to encounter that reservoir. The greater the reservoir stratification coefficient, the greater the reservoir thickness, and the better the sand body connectivity may be. This indicates a better continuity of the plane, and the corresponding quality sand body extension in the plane will be larger. In contrast, the smaller the reservoir stratification coefficient, the stronger the heterogeneity of the reservoir plane, and the unconnectivity of the sand body occurs between wells in the same layer section. This is generally considered a higher degree of superposition of the sand body in the reservoir, usually multilayered, multilateral, or isolated

(2) The storage coefficient ($\phi * h * S_o$) is the multiplication of the average porosity of a reservoir (ϕ) with the effective thickness of the reservoir (h) and oil saturation (S_o) of the section. The energy storage coefficient reflects the amount of oil that can be stored in the reservoir of the section [20]. The larger the energy storage coefficient, the more oil can be stored. Besides, in the study of middle- and low-permeability sandstone reservoirs, the size of the energy storage coefficient can be used to evaluate the quality of middle- and low-permeability sandstone reservoirs. The larger the energy storage coefficient, the better the reservoir

(3) The stratigraphic coefficient ($k * h$) is the product of reservoir permeability (k) and reservoir thickness (h). This has a strong correlation with reservoir physical parameters. The relationship between stratigraphic coefficients and production capacity can be analyzed to some extent from the reservoir percolation capacity [21, 22]. When the stratigraphic coefficient is larger, the reservoir material is better, and the percolation capacity is also stronger. Therefore, it is believed that the production capacity is affected to some extent, and the reason is related to the stratigraphic coefficient, a reservoir material parameter

4. Preferred Method for Selection of Reservoir Sweet Spots

The reservoir classification is conducted using the weighting analysis method. This concentrates all the relevant information about the original variables of the study object and then determines the weights of different factors and the corresponding evaluation criteria. Some scholars have been using this method to evaluate the reservoir in the study area Zhongqui 58, mainly applied to the carbonaceous volcanic reservoir, and established evaluation criteria in the study area [23, 24]. The reservoir sweet spots were evaluated as follows. The parameters of evaluation indicators were first defined, and then the evaluation indicators were standardized by assigning a certain weighting factor to each of the established evaluation indicators. On this basis, the following two aspects were carried out: one is the calculation for the reservoir comprehensive evaluation coefficient; the other is the classification for the reservoir type. Finally, the evaluation results of reservoir sweet spot classification can be successfully applied in the target area.

The set of factors established can be recorded as follows:

$$U = \{u_1, u_2, \cdots, u_m\}, \tag{1}$$

where $u_1, u_2, \cdots, u_m$ are evaluation factors.

In this study, according to the principle of sweet spot preferences, a comprehensive set of evaluation indexes, relatively clear and widely available, was set as follows based on the actual study area: reservoir stratification coefficient, energy storage coefficient, and stratigraphic coefficient. The set of factors established accordingly is recorded as follows:

$$U = \left\{ \frac{h_i}{H \times n_i}, \phi h_i S_o, K h_i \right\}. \tag{2}$$

A comment set is considered an evaluation level criterion and also feedback to the sample set to be evaluated through its resulting descriptions and judgments. A rating set can not only be a set of qualitative descriptions such as Class I, Class II, and Class III but also be considered a set of quantitative values such as 0.2, 0.4, and 0.6. Usually, the evaluation ratings are divided into 2-6, which can be labeled as follows:

$$V = \{v_1, v_2, \cdots, v_n\}, \tag{3}$$

where $v_1, v_2, \cdots, v_n$ are rating levels.

Based on the general habit of reservoir classification, combined with the development and index characteristics of the reservoir in the Sha 3 Member I oil group of the XA block in the study area, the comments were classified into three levels, and a set of comments was created as follows:

$$V = \{\text{I}, \text{II}, \text{III}\}. \tag{4}$$

The weight set refers to the interrelationship between the evaluation factors; i.e., the importance of each parameter has a certain degree of influence on the overall characteristics of the reservoir. According to past experience and studies, many methods are available to determine the weight. However, in general, the methods can be divided into two categories: one is the subjective assignment method, and the other is the objective assignment method. Commonly used methods include hierarchical analysis, principal component analysis, entropy weighting, and feature vector methods. Among them, the entropy weighting method first takes the entropy information as the primary basis and then determines the weight score according to the difference of indicators [23, 25]. It is relatively objective, which to some extent makes it possible to avoid the uncertainty of judgment caused by human factors.

The final set of weights established can be denoted as follows:

$$A = \{a_1, a_2, \cdots, a_n\}, \tag{5}$$

where $a_1, a_2, \cdots, a_n$ are weights.

Table 2: Classification criteria for reservoir " sweet spot" indicators.

Reservoir classification	Reservoir stratification factor ($h/H * n$)	Energy storage coefficient ($\varphi h S_o$/m)	Stratigraphic coefficient (kh/mD·m)
Class I	>0.63	>1.16	>181
Class II	$0.51 < h/H * n < 0.62$	$0.75 < \varphi h S_o < 1.15$	$86 < kh < 180$
Class III	<0.50	<0.74	<85

Table 3: Comprehensive classification evaluation criteria.

Reservoir stratification factor	Energy storage coefficient			Stratigraphic coefficient
	Class I	Class II	Class III	
Class I	Class I	Class I	Class II	Class I
Class II	Class I	Class II	Class III	Class II
Class III	Class II	Class III	Class III	Class III

In this study, the entropy weighting method is preferred in determining the weight scores of different evaluation indicators. Generally, if more information is available, the greater the variation of established indicators, and the greater the importance of indicators in the comprehensive evaluation. Thus, the sample data obtained from 134 wells in the study area were substituted into Equations (A.1)–(A.3) (see the appendix) to establish the weight scores among the indicators of the factor set.

Establish weight sets for

$$A = \{0.20, 0.45, 0.35\}. \quad (6)$$

The score ranking of all reservoir sweet spots was targeted for evaluation considering the attributes and relative importance of each "sweet spot" indicator. The risk to the development of low-permeability multiple reservoirs lies in the uncertainty as to the weight of indicators of reservoir sweet spots. To some extent, this reflects the failure rate of upcoming projects or studies. The overall score for the sweet spots of the ith reservoir can be evaluated considering the weighting factor as follows:

$$P_i' = \left(\frac{h_i}{H * n}\right) * a_1 + (\phi * h_i * S_o) * a_2 + (K * h_i) * a_3. \quad (7)$$

5. Application and Discussion

5.1. Division of Oil Groups. The main destination level of the XA block is the Sha 3 Member. According to the stratigraphic comparison, Es_3 can be divided into two oil groups: Es_3 I and Es_3 II. In the four small layers of the sand group in the Es_3 I oil group, the 1st small layer is relatively developed in the axis of the block, and the sand body is thinned from east to west until the tip is extinguished. The 2nd and 3rd small layers are the main production layer of the block with good connectivity and relatively good reservoir material, and the average effective thickness is 10 m. The 1st and 4th small layers are relatively poorly developed, and the average effective thickness of the 4th small layer is 6 m.

5.2. Evaluation of Reservoir Sweet Spot Classification. The reservoir in the Shahejie Formation in the XA block belongs to the medium-low-porosity and low-extra-low-permeability reservoirs. In this reservoir evaluation classification, three key evaluation indicators were selected to help in the evaluation of reservoirs: "reservoir stratification coefficient," "energy storage coefficient," and "stratigraphic coefficient." The single-factor classification criteria for Class I, Class II, and Class III reservoirs were established for each of the three indices based on the actual conditions of the XA block reservoir and production (Table 2).

To perform a comprehensive evaluation of reservoir sweet spots, three evaluation indicators were integrated. In the evaluation, it is necessary to provide a comprehensive reservoir evaluation classification based on the weights of three coefficients. However, considering the practicality of the field, the integration method as shown in Table 3 was used. Using this method, Class I, Class II, and Class III reservoirs can be easily and quickly identified.

Based on the above criteria, the sweet spots of Class I, Class II, and Class III reservoirs were identified in the XA block. The physical properties of reservoirs in different layers and areas show obvious differences. Most of the sweet spots with better physical properties are located in the Class I and Class II reservoir areas, while the Class III reservoir area is the distribution area of sweet spots of low-abundance reservoirs.

5.3. Analysis of the Evaluation Effect of Reservoir Classification. By applying the above reservoir sweet spot comprehensive evaluation classification results, combined with the completed drilling and test wells, test production, and production dynamics of the XA block, the effective thickness reservoir delineation zones of Class I, Class II, and Class III in the Sha 3 Member I oil group of the block are given. The effective thickness of Class I, Class II, and Class III reserves in the Sha 3 Member I oil group of the block is given, and the production dynamics are superimposed on the map (Figure 5).

There are 51 wells in the XA block testing oil in the Sha 3 Member oil formation. Among them, 24 wells are

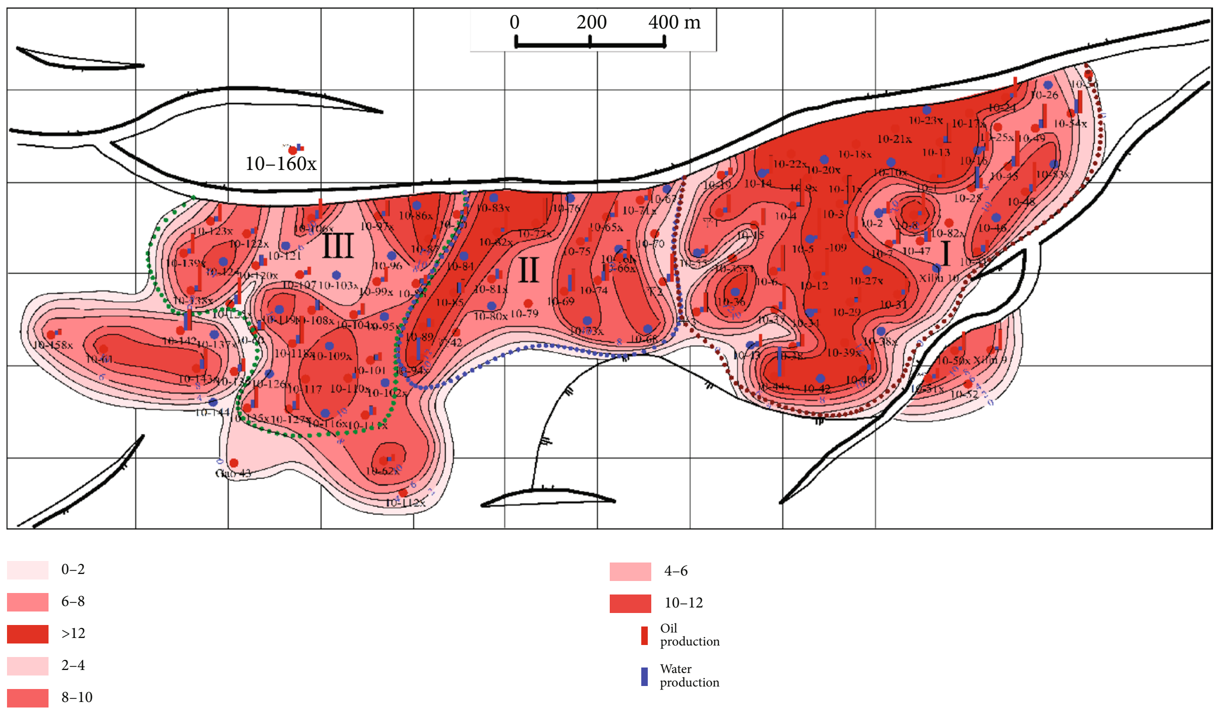

Figure 5: Overlapping map of the effective thickness and production dynamics of the Es_3 I oil group in the XA fault block.

conventional wells with an average daily oil production of 0.9 t/d and average daily water production of 1.5 m^3/d; 43 wells are fracture testing oil with an average daily oil production of 8.4 t/d and average daily water production of 8.8 m^3/d. Seven of the wells showed low production with an average daily oil production of 1.5 t/d and average daily water production of 12.6 m^3/d; most of the wells are located in the Class III area of the target block with an initial average daily production of 8.2 t/d, a current average daily production of 1.6 t/d, and an average cumulative production of 283.7 t. The average daily oil production of the 34 wells in Class I of the main part of the block is 10.2 t/d. Only three of the 12 wells in the producing Sha 3 Member have good production condition, concentrated in the Class I area near the main part of the old block with an initial average daily oil production of 15.6 t/d. At present, the average daily production is 9.2 t/d, and the average cumulative production is 8830 t. The remaining nine wells are located in the Class II area in a section of the district with an initial average daily production of 4.2 t/d, a current average daily production of 1.8 t/d, and an average cumulative production of 990 t. The results show that the evaluation criteria are closely related to development and production and reflect certain actual production characteristics.

In summary, most of the good physical properties and production dynamics are sweet spots of Class I and Class II reservoirs, while the sweet spots of Class III reservoirs are low-abundance reservoir distribution areas. It is important to note that the low-abundance reservoir sweet spot zone does not represent a reservoir, which is still considered to exist within the sand distribution, although the reservoir has relatively poor physical properties.

6. Summary and Conclusions

This work studies the classification and evaluation methods of geological sweets for low-permeability multilayered reservoirs. Considering the characteristics of low-permeability oil reservoirs, three evaluation indicators are proposed, and hence, the evaluation indicators were standardized by assigning a certain weighting factor to each of the established evaluation indicators to calculate the comprehensive evaluation coefficient of the reservoir. Finally, the evaluation results of reservoir sweet spot classification can be successfully applied in the target area. The main conclusions are summarized as follows:

(i) The reservoir stratification coefficient, energy storage coefficient, and stratigraphic coefficient are proposed to describe sweet spots. Based on different combinations of preferred evaluation parameters, incorporate a weighting analysis to provide quantitative criteria. The reservoir stratification coefficient characterizes the scale of extension, continuity, and connectivity of reservoirs in the plane, proposed on the basis of the lower limit of the effective thickness of the reservoir. The division of the effective thickness of the reservoir and the number of layers is especially considered in this study

(ii) A case study of the Sha 3 Member I oil group in the XA block considered the reservoirs and production. Most of the XA block are sweet spots of Class I and Class II reservoirs, while Class III reservoirs are low-abundance reservoir distribution areas. Therefore, this study has certain guidance and reference significance for the classification and evaluation of similar low-permeability multioil reservoirs

(iii) The advantage of this work is that based on the different combinations of five key reservoir evaluation parameters that have been selected, a classification method for reservoir evaluation has been established through principal factor analysis and weighting analysis. The area for improvement is the lack of consideration of engineering factors such as pressure and fluid properties

Appendix

The formula for the entropy weighting method can be expressed as follows:

$$P_{ki} = \frac{x_{ki}}{\sum_{k=1}^{k} x_{ki}}, \quad i = 1, 2, \cdots, n\,;\ k = 1, 2, \cdots, K, \tag{A.1}$$

$$E_i = -\frac{1}{\ln K} \sum_{k=1}^{K} \left(P_{ki} \ln P_{ki}\right), \tag{A.2}$$

$$a_i = \frac{1 - E_i}{\sum_{i=1}^{n} \left(1 - E_i\right)}, \tag{A.3}$$

where k is the number of evaluation sample objects; X_{ki} is the sample data for indicator i of kth evaluation object; P_{ki} is the proportion of data obtained from the kth evaluation sample for indicator i; E_i is the information entropy of indicator i, dimensionless; a_i is the weight of indicator i, dimensionless.

Nomenclature

h: Effective thickness of the reservoir
H: Thickness of the reservoir
n: Number of reservoir layers
ϕ: Effective porosity
S_o: Oil saturation
k: Permeability.

Data Availability

All of the data used to support the findings of this study are included in the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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