Article

# Method and Application of Reservoir Unit Division in Continental Faulted Lacustrine Basin: An Example from the L70 Fault Block in Raoyang Sag

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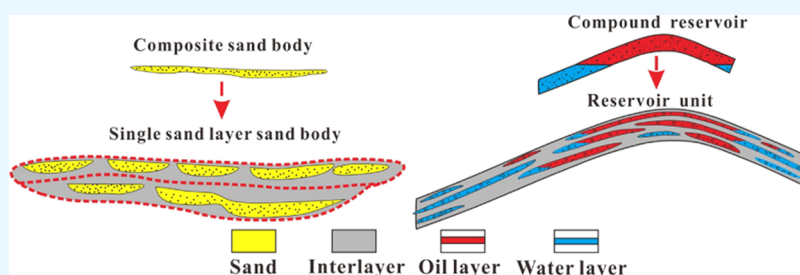
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**ABSTRACT:** The continental faulted lacustrine basin is an important type of continental oil and gas basin with typical compound oil and gas accumulation characteristics. The traditional petroleum geological theory usually makes a general analysis of multiple reservoirs. It uses the structural model to understand the reservoir and has a vague understanding of the reservoir. The actual exploration is inconsistent with the traditional theory, which restricts exploration and development. In this case, taking the lower submember of Sha 1 of Shahejie Formation of L70 fault block in Raoyang sag as an example, the concept of reservoir unit is put forward, and the reservoir is redivided using the "four diagrams and four steps" method, the oil−water distribution is clarified, the type of reservoir unit is defined, and multiple potential reservoir units are proposed. It enriches and perfects the traditional petroleum geological theory, provides a new research method and idea for petroleum exploration and development, and ushers in new opportunities for the developed old oil fields.

## 1. INTRODUCTION

The continental faulted lake basin is an important type of continental petroliferous basin in China. It has also become an important tight oil exploration area in recent years. It has the characteristics of a small area, shallow water body, and easy to be affected by short-term climate fluctuations.[1−3] It has typical compound oil and gas accumulation characteristics. After long-term exploration and development, it has generally entered a mature exploration stage, but the exploration degree and geological understanding are uneven; structural reservoirs have a high degree of knowledge, while subtle reservoirs such as lithology have a relatively low degree of knowledge. They are the main body of residual resource potential. How to effectively explore such residual oil and gas resource potential is necessary to have a new understanding and research on reservoirs and break the shackles of traditional exploration.

For traditional reservoirs, a reservoir has a uniform pressure and oil−water interface.[4] In the same structural trap, only the corresponding single structural oil and gas reservoir is developed, and the trap type is corresponding to the reservoir type. In the same structural trap, the sand body is single and developed continuously, and the reservoir type is relatively

single, with a unified oil−water interface (Figure 1a). After exploration and development,[5] a single trap reservoir has strong heterogeneity. For a single trap reservoir, there may be no unified oil−water interface, and the traditional geological theory is no longer fully applicable. In the rolling exploration and development stage, although a large number of new dynamic and static data have been added, the study on reservoir genesis and enrichment law is rarely carried out again from the overall consideration of the zone. The main understanding of reservoir-forming geology is still in the early exploration stage to a large extent.[6] The single reservoir in the traditional petroleum geological theory is usually a compound reservoir. The compound reservoir refers to the fact that each reservoir unit is controlled by lithology, physical property, and structure on the same structural unit, and each
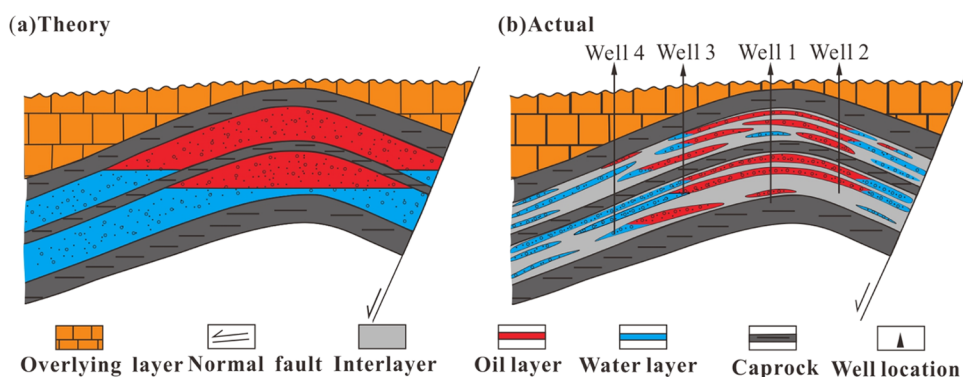
**Figure 1.** (a and b) Diagrams of the relationship between the reservoir and trap (a: theory; b: actual).
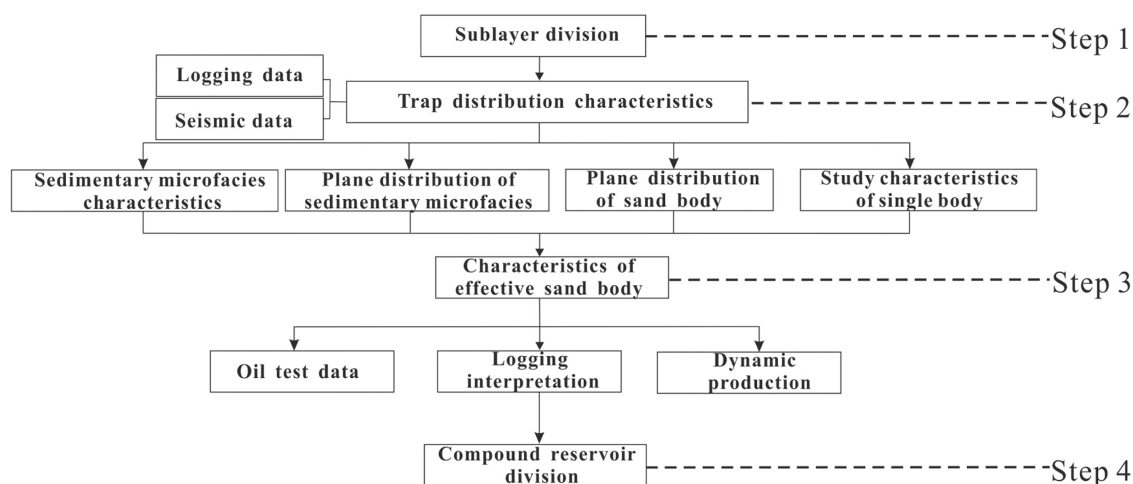


**Figure 2.** Reservoir unit division steps.

reservoir unit is independent of each other and stored together in the sand body to form a large-scale and complex oil–gas reservoir with a complex oil–water system. A compound reservoir is a generalized reservoir composed of multiple reservoir units in the same layer on the local structure. With the complex oil–water system and various reservoir types, it is an accumulation unit between oil reservoirs, and oil fields, and is the specific target of oil and gas exploration.[7] According to the actual exploration and development, it is found that within the same structural trap, sand bodies are not simply developed continuously. In fact, they are independent of each other, resulting in the symbiosis of multiple reservoirs. The types of reservoirs are diverse. Each individual reservoir has its independent trap conditions, and the oil–water interface is not unified (Figure 1b). In this regard, scholars at home and abroad have put forward a series of methods. The flow unit was proposed by Hearn et al.[8] They believe that the flow unit is a reservoir with similar porosity, permeability, and layer characteristics in the vertical and horizontal continuous sand bodies, and the heterogeneity of the reservoir can be controlled by the flow unit. The flow unit is a further subdivision of the reservoir. It not only reflects the basic characteristics of fluid flow in the reservoir but also reflects the changes in the petrophysical properties of the reservoir.[9–12] It solves the internal heterogeneity of the compound reservoir and is applied to reservoir evaluation in the oil field exploration stage and residual oil distribution and prediction in the development stage.[13] The concept and research method of reservoir unit are the sublimation and application of the definition based on the

petroleum geological theory based on the concept of "flow unit". The flow unit is a development method proposed for the oil field development stage, while the reservoir unit is a supplement and challenge to the traditional geological theory and is proposed based on the accumulation and experience of exploration and development.[14,15] That is to say, the flow unit is only a development method at the stage of oil field development, while the reservoir unit is a theoretical challenge and supplement to the traditional petroleum geological theory, a new understanding of the reservoir from the system, and then systematically solves the exploration and development problems and guides the exploration and development.

Based on the exploration and development data for many years, the author takes the L70 fault block $Es_1^L$ (the lower submember of Sha 1 of Shahejie Formation) in Raoyang sag as an example to study the division of reservoir units. Through the fine dissection of reservoir units, the types of reservoir units are defined, the oil–water distribution is clarified, and the oil–water contradiction is solved. The proposal of a reservoir unit breaks the bondage of traditional petroleum geology theory and provides a new method and idea for petroleum geology.

## 2. CONCEPT AND DIVISION METHOD OF THE RESERVOIR UNIT

**2.1. Concept of the Reservoir Unit.** The reservoir unit is put forward to meet the challenge of traditional petroleum geological theory in exploration and development. The reservoir unit refers to the smallest oil-bearing monomer that
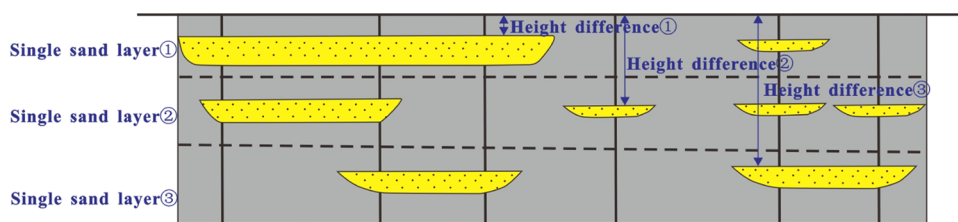
**Figure 3.** Schematic diagram of equal elevation comparison.

has a unified oil−water interface and pressure system in the reservoir.[16] Each reservoir unit, as an independent individual, is the lowest level of a compound reservoir with different shapes. It may be composed of a single sand body or multiple single sand bodies. Different from the compound reservoir, each reservoir unit is interconnected and has the same structure. The reservoir is relatively closed and has an independent oil−water system. The reservoir unit is the smallest oil-bearing unit that cannot be further separated after a detailed study of the compound reservoir.

**2.2. Reservoir Unit Division Method.** Reservoir unit division is to restudy and analyze the traditional compound reservoir, clarify the research idea according to the concept of reservoir unit, and accurately divide different reservoir units and determine their distribution range using the "four diagrams and four steps" method (Figure 2).

The first step is to carry out a fine small layer division and comparison for the study area, then establish a small layer data table, and then draw a structural map of oil-bearing small layers in combination with the structure and other data.

The second step is to integrate seismic data and logging data to clarify the trap distribution characteristics and carry out high-precision seismic acquisition and continuous processing for the study area in the exploration and development and determine the structure and fault.

The third step is to carry out effective sand body research based on small layer division and trap characteristics. First, the sedimentary characteristics are studied, then the plane distribution of sedimentary microfacies and sand body is determined, and then the sand body characteristics are studied to provide help for the division of reservoir units. (1) Taking the small layer as the research unit, combined with previous studies, fine sedimentary microfacies research is carried out according to the sedimentary characteristics and the sedimentary facies and their types are clarified. (2) Based on the study of sedimentary microfacies characteristics, the plane distribution map of sedimentary microfacies is prepared in combination with core data to clarify the connectivity of sand bodies and determine the distribution boundary and shape of sand bodies. (3) According to the characteristics of sedimentary microfacies and their plane distribution map, the plane distribution map of the sand body is prepared according to the sand thickness data to clarify the plane distribution characteristics of the sand body. (4) The characteristics of a single sand body in the study area are studied, and the connection and contact relationship of the sand body in the plane and longitudinal directions are analyzed.

Finally, combined with the oil test data, logging interpretation, and dynamic production data, the oil−water distribution is defined, the reservoir unit is identified, and the compound reservoir is divided into a single sand body level reservoir, that is, the reservoir unit. In short, the method of reservoir unit division is to divide the complex oil formation into small levels based on the study of sedimentary microfacies and sand bodies in combination with production, logging, oil testing, and other data and then divide the small level into single sand layer level to define the oil−water boundary and determine the reservoir range. The "four diagrams" refer to the plane distribution of sedimentary microfacies, the plane distribution of sand bodies, the plane distribution of single sand bodies, and the plane of single sand reservoir units.

The most important step of reservoir unit division is the study of single sand body characteristics. A single sand body is a unit formed by a single cause during the development of the fluvial facies sedimentary system. It is continuously and independently developed in the small layer under the influence of the interlayer. In the vertical direction, the single sand body is not connected,[17,18] which is the most basic component unit of the small layer. Different sand bodies are affected by such factors as facies control type, development scale, and sedimentary period, and contact with each other is independent of each other in different positional relationships in space, forming complex and diverse sand body contact relationships in the stratum.[19] Therefore, the number of single sand bodies in different small layers is also different. There may be only one set of single sand bodies developed independently or multiple sets of single sand bodies developed continuously. Through well-logging data and lithology data, the interlayer can be identified, and then the composite sand body can be divided into several single sand bodies. The storage and migration of oil and gas in the formation pass through the sand body, which is the basis and key to the study of oil and gas accumulation.[20] The study of the reservoir unit is to disassemble the compound reservoir, and the main task of the study is to clarify the characteristics of the oil-bearing sand body in the formation. The single sand layer is the most basic unit of the sedimentary sand body in the stratum,[21,22] and it is also the basis for reservoir unit division and characterization. The traditional reservoir research work is only carried out at a small level, ignoring the connectivity between single sand bodies in the layer. Therefore, the premise of studying the structure and connectivity relationship in the reservoir is to identify and divide the single sand body,[23,24] which determines that the division of reservoir units must be carried out at the level of the single sand body. In regional stratigraphic research, high-resolution sequence stratigraphy is often used for stratigraphic correlation and division. However, for small-scale reservoir research areas, the use of sequence stratigraphy has certain limitations.[25] For stratigraphic correlation and division of such research areas, sand body and other elevation correlation methods are more appropriate choices.[26,27] It is generally believed that the interface of the middle and small layers in the fluvial facies sedimentary system is the isochronous interface. For the sand bodies developed in the same sedimentary period, the elevation difference from the top surface to the adjacent isochronous surface should be
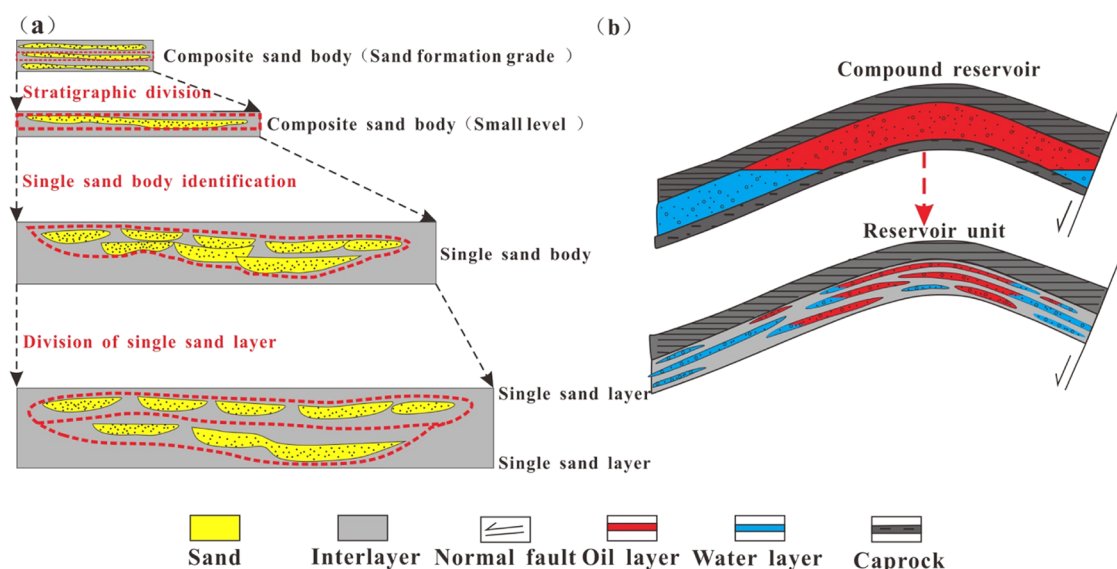
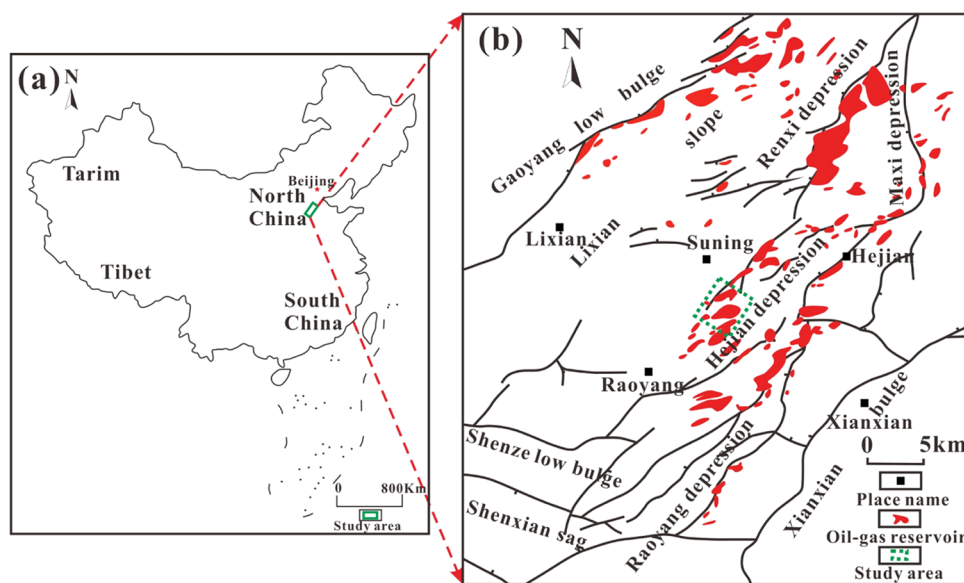**Figure 4.** Division steps of single sand layer (a) and split diagram of the compound reservoir (b).



**Figure 5.** Study area location maps (a and b) (a: in China; b: in Raoyang sag).

approximately equal, that is, the sand bodies developed in the same sedimentary period should have approximately equal elevations.[28] Therefore, in the small layer, the single sand body similar to the elevation difference of the layer interface can be divided into the same sedimentary time unit, and a single sand body combination, i.e., a single sand layer, can be formed on the plane (Figure 3).

In short, the method of reservoir unit division is to carry out detailed research on sand bodies based on the research of seismic and logging data, divide the sand bodies of compound oil formation into small-scale sand bodies, and then divide the small-scale sand bodies into single sand bodies, combine the single sand bodies into single sand layer sand bodies according to the vertical and lateral connectivity of sand bodies (Figure 4a), determine the oil−water boundary in combination with oil test data, logging interpretation, and dynamic production data, and split the complex small-scale reservoir into the single sand reservoir, i.e., reservoir unit (Figure 4b).

## 3. APPLICATION IN THE L70 FAULT BLOCK

**3.1. Regional Geological Overview.** Dawangzhuang oil field is geographically located in the middle of Raoyang sag in Bohai Bay Basin and structurally located in the Suning Dawangzhuang structural belt in Raoyang sag. In the central uplift belt, the Dawangzhuang oil field is clamped by the Suning sag trough and Hejian sag trough, showing an obvious "high-in-sag" anticline structure[29] (Figure 5). L70 fault block, which belongs to the Dawangzhuang oil field, is located in the middle and north of the Dawangzhuang oil field. It belongs to the core of the Dawangzhuang oil field. The exploration area is about 11 km². As an old exploration area, the main exploration and development horizons are $Ed_3$ (the third section of the east) and $Es_1^U$ (the upper member of Sha 1 of Shahejie Formation).[30] L70 fault block in the research target area is located in the south of Dawangzhuang, including four main well blocks L483, L474, L70-39, and L477 (Figure 6). The main oil-bearing horizons are $Ed_3$, $Es_1$, and $Es_3$.[31,32]
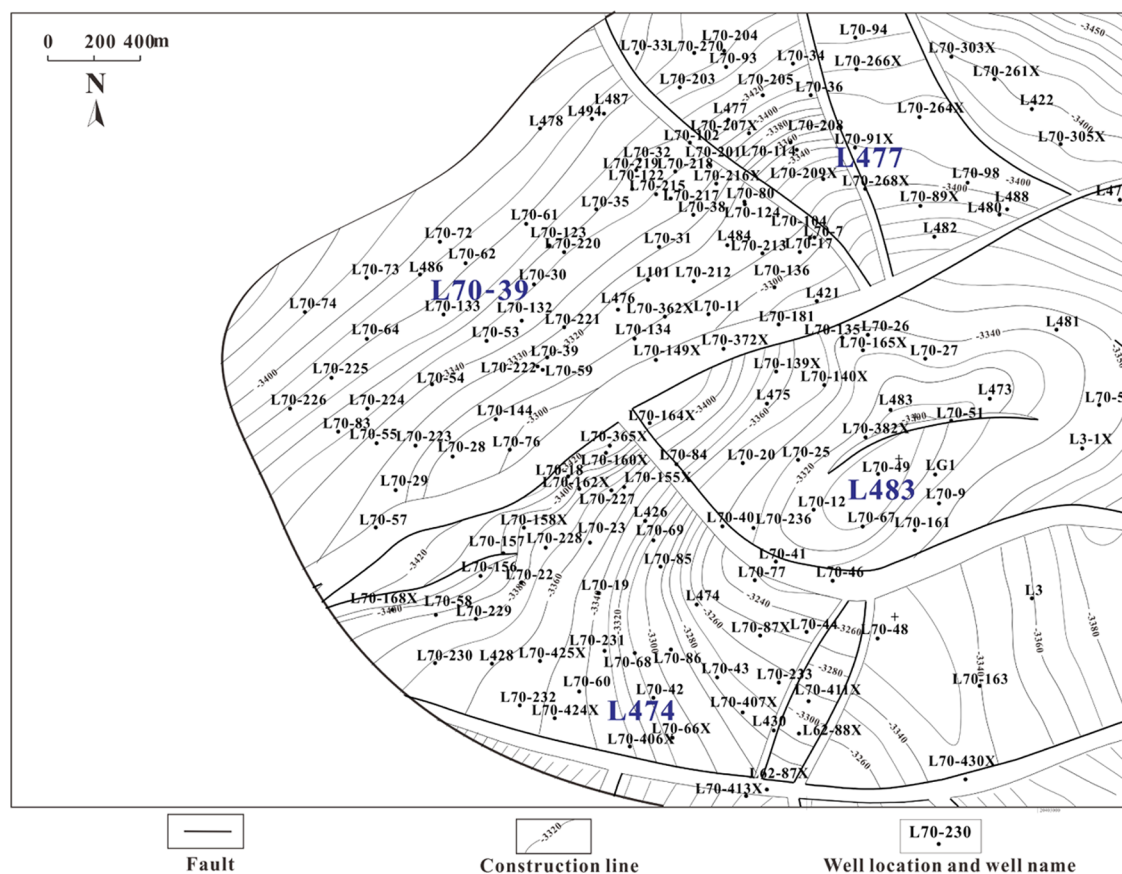
**Figure 6.** Structural plan of the L70 fault block.

Based on the study of oil formation layering, sand body research and fine layering of oil formation are carried out. The sequence boundary identification of oil formation is mainly determined by the analysis of logging response characteristics, but the logging response characteristics are not obvious, so it needs to be analyzed in combination with multiple data, such as lithologic association, sand mud ratio, and cycle characteristics. Based on these data and production practices, the author has identified the oil formation interface in the study area. Based on the oil formation interface identification, the author has identified the fifth-order sequence interface using maximum entropy spectrum analysis, wavelet transform, and base level cycle and solved the actual situation that the logging response characteristics are not obvious.[33,34] According to the actual situation of the study area, $Es_1^L$ can be mainly divided into oil formation I (① ② small layer), oil formation II (① ② small layer), and oil formation III (① ② small layer) (Table 1).

**3.2. Reservoir Unit Division.** Taking the L70 fault block in Raoyang sag as an example, the reservoir unit division of

$Es_1^L$ is studied through the division method of four diagrams and four steps.

*3.2.1. Analysis of Trap Characteristics.* High-precision seismic acquisition and continuous processing were carried out for the L70 fault block. The trap distribution characteristics and structures and faults were determined through seismic data and logging data. Through detailed seismic data, it is clear that the L70 fault block in Raoyang sag is not a trap controlled by a single structure as traditionally thought but mainly develops lithologic traps, structural lithologic composite traps, and lithologic structural composite traps.

*3.2.2. Characteristics of Effective Sand Body.* Based on the small layer division, effective sand body research has been carried out. First, the characteristics of sedimentary microfacies are studied, then the plane distribution of sedimentary microfacies and bodies are determined, and then the characteristics of the sand body are studied.

*3.2.2.1. Characteristics of Sedimentary Microfacies.* Based on the division of sequence stratigraphy, combined with core data, logging data, sedimentary structure, and other data, this study selects the $Es_1^L$ horizon of the L70 fault block in Raoyang sag to study its sedimentarytocies to provide help for the division of reservoir units. The study area is located in the Dawangzhuang structural belt, and the provenance comes from the Gaoyang low uplift in the West and the Shenze low uplift in the southwest. $Es_1^L$ stratum in the study area belongs to Braided River Delta and lacustrine facies, mainly developing shore shallow lake surfaces and delta front surfaces.[35−38] L70 fault block is located in the central uplift zone of Raoyang sag, belonging to the area where rivers enter lake.[39] $Es_1^L$ mainly develops beach bars, and some develop delta front. The

**Table 1. Stratification of the Study Area**

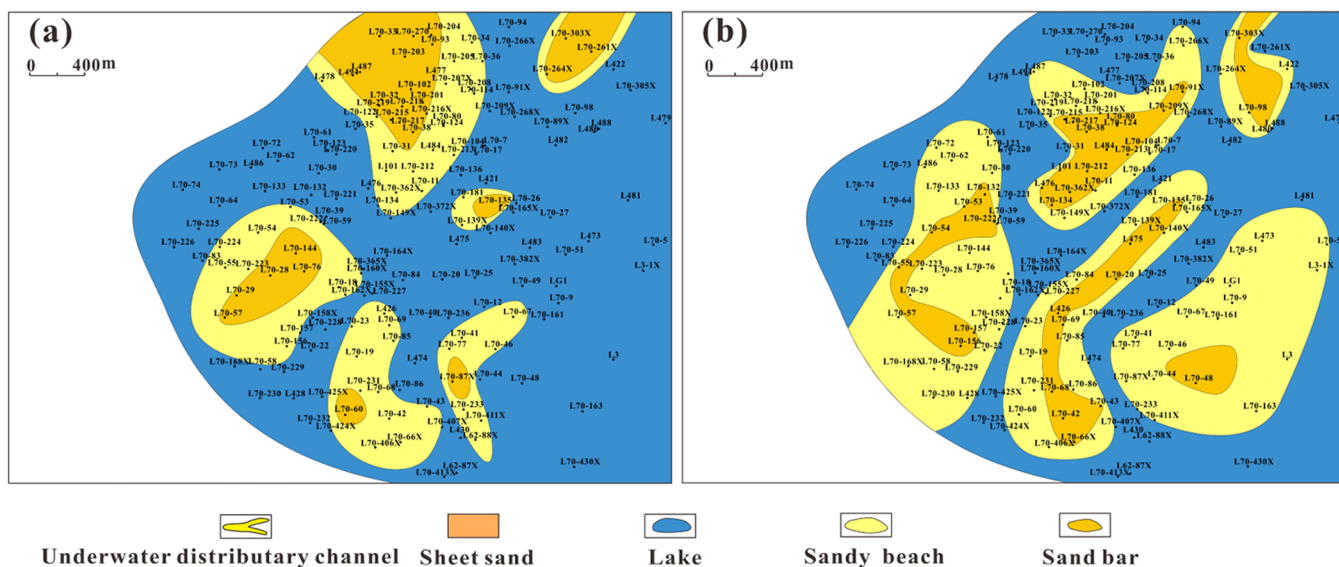| stratigraphic system | | | layered | |
|---|---|---|---|---|
| formation | member | submember | oil formation | small layer |
| Shahejie formation | $Es_1$ | $Es_1^L$ | $Es_1^L$I | $Es_1^L$I-1 |
| | | | | $Es_1^L$I-2 |
| | | | $Es_1^L$II | $Es_1^L$II-1 |
| | | | | $Es_1^L$II-2 |
| | | | $Es_1^L$III | $Es1^L$III-1 |
| | | | | $Es_1^L$III-2 |

**Figure 7.** $Es_1^L$ I sedimentary microfacies diagrams (a and b) of the L70 block (a: $Es_1^L$ I-1 sedimentary microfacies diagram; b: $Es_1^L$ I-2 sedimentary microfacies diagram).
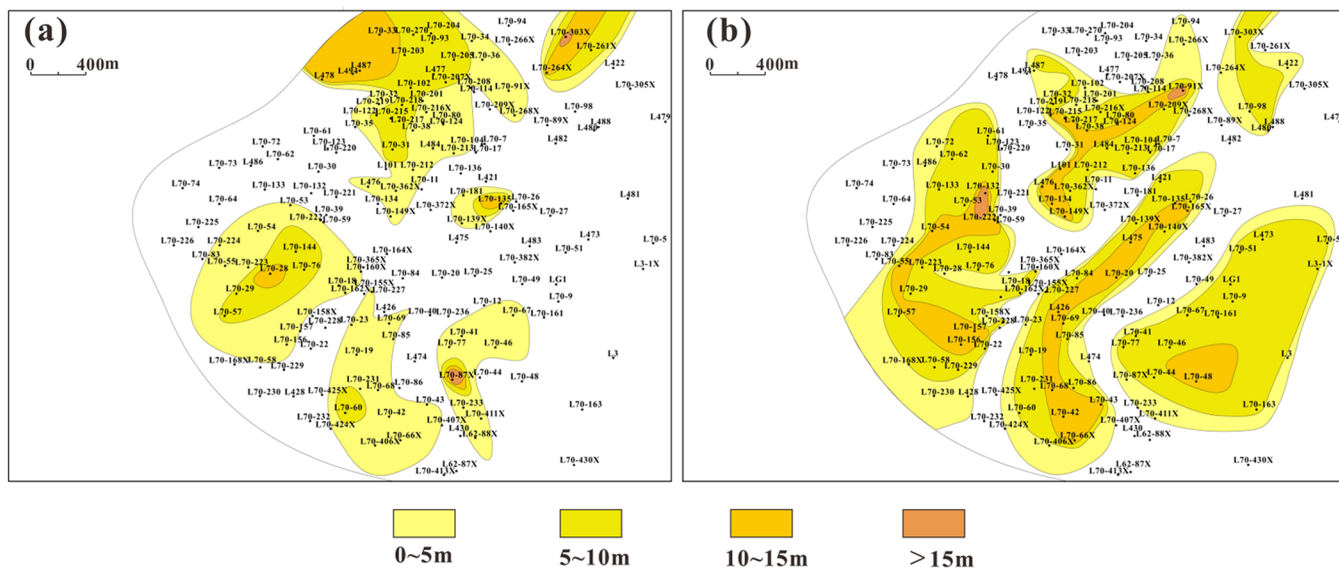


**Figure 8.** $Es_1^L$ I sand body distribution diagrams (a and b) of the L70 block (a: $Es_1^L$ I-1 sand body distribution diagram; b: $Es_1^L$ I -2 sand body distribution diagram).

microfacies of beach bar deposits are mainly sand bars, sandy beaches, and shallow lake mud. The main body of the delta front develops underwater distributary channels and sheet sands.[40] Among them, sand bars and underwater distributary channels are dominant microfacies, which are favorable areas for sand body development, with good physical properties and great potential for oil and gas injection.

*3.2.2.2. Plane Distribution of Sedimentary Microfacies.* During the period from $Es_2$ (the second member of Shahejie Formation) to $Es_1^L$II, under the background of stratum uplift, the supply rate of material sources remained in the medium range, and sandy beaches and sand bars were inherited in the study area. In $Es_1^U$, the tectonic uplift was further enhanced, and the lake area was sharply reduced, mainly river sediments.[41] During the $Es_1^L$ stage of the L70 fault block in the study area, water mainly experienced the process of water inflow, and the water area gradually became larger. The early

climate of $Es_1$ began to turn cool and humid, and the late $Es_1$ completely turned into a warm and humid climate. Therefore, underwater distributary channels and sheet sands are widely developed in oil formations III in the study area, while beach bars are widely developed in oil formations I and II. The development range of the shoal and bar gradually becomes larger, and the sand body of oil formation I has a large development range and good physical properties (Figure 7).

*3.2.2.3. Plane Distribution of Sand Body.* According to the plane characteristics of sedimentary microfacies and the production data of oil testing and logging interpretation data, the thickness of a single well sand body is analyzed, and the plane distribution characteristics of the sand body in the study area are analyzed based on the subdividing small layers. It is found that the sedimentary sand body of the L70 fault block is consistent with the distribution characteristics of microfacies, and the sand body thickness of the sand bar and underwater
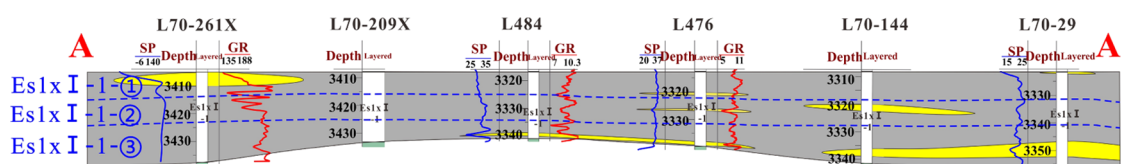
**Figure 9.** Characteristics of the single sand layer in small layer $Es_1^L$ I-1 of well-connected well in block L70.
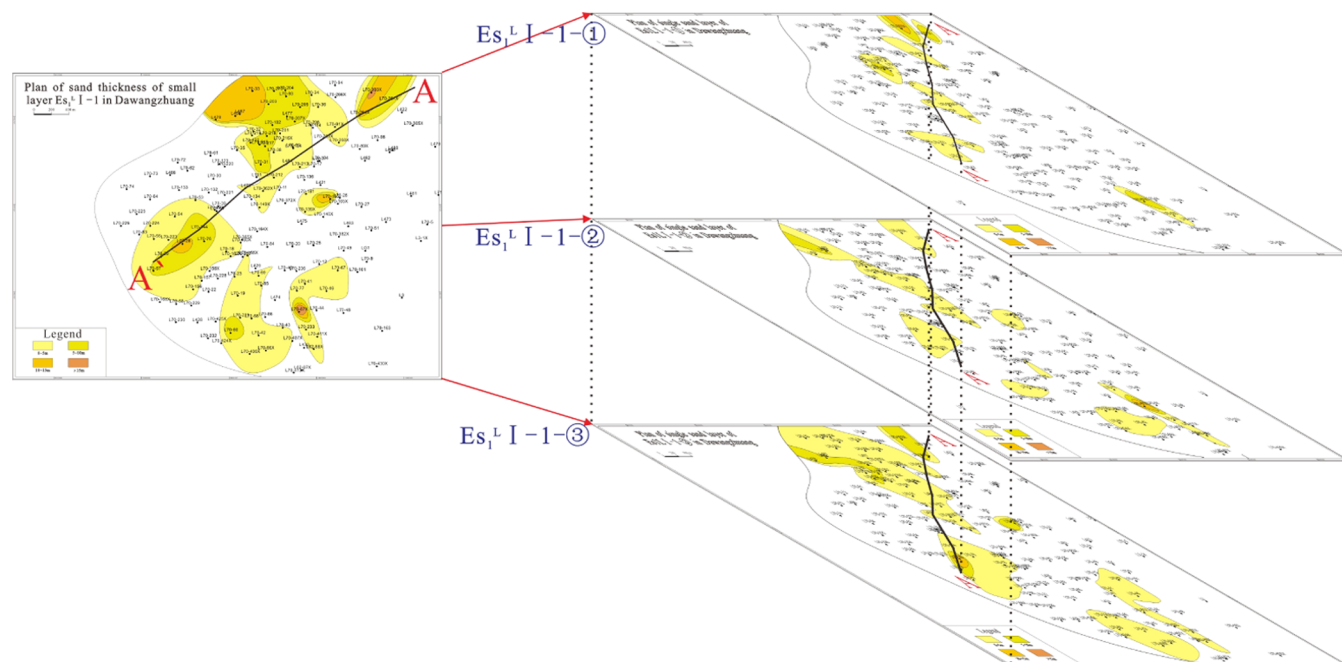


**Figure 10.** Vertical stereogram of the single sand layer in small layer $Es_1^L$ I-1 of fault block L70.
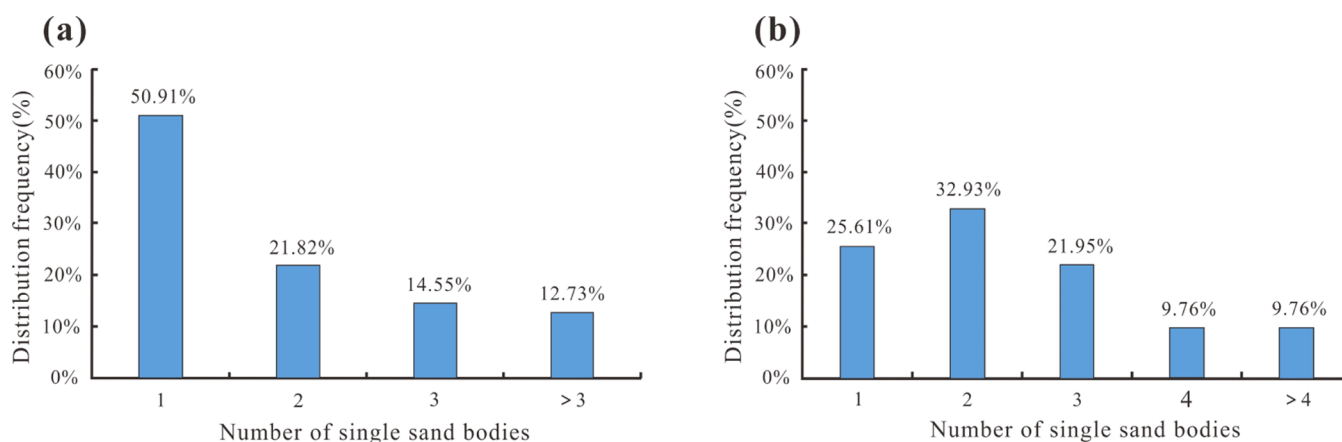


**Figure 11.** Frequency diagrams (a and b) for quantity distribution of single well-controlled sand bodies in each small layer of the $Es_1^L$I oil formation of the L70 block (a: distribution frequency of a single sand body controlled by a single well in small layer $Es_1^L$ I-1; b: distribution frequency of the single sand body controlled by a single well in small layer $Es_1^L$ I-2).

distributary channel developed in the fault block is generally large. The thickness of the sand body in small layer ② of oil formation I (Figure 8) and oil formation III is relatively large. The sand bodies are distributed in an isolated form and scattered, and the sand bodies are not connected. The sand bodies near the source in the West are better developed, and the sand bodies far away from the source in the East are poorly developed.

*3.2.2.4. Study on the Characteristics of Single Sand Body.* According to our previous research on sedimentary microfacies

and sand body distribution, we selected $Es_1^L$ I oil formation with a well-developed sand body in the study area and conducted a series of related single sand body studies, which laid a foundation for reservoir unit division.

Taking the study of small layer $Es_1^L$ I-1 as an example based on the identification and division of a single sand body, the elevation difference between the top surface of each single sand body in the small layer and the top interface of the small layer is compared according to the isochronal comparison principle. According to the results of the isochronal comparison of a
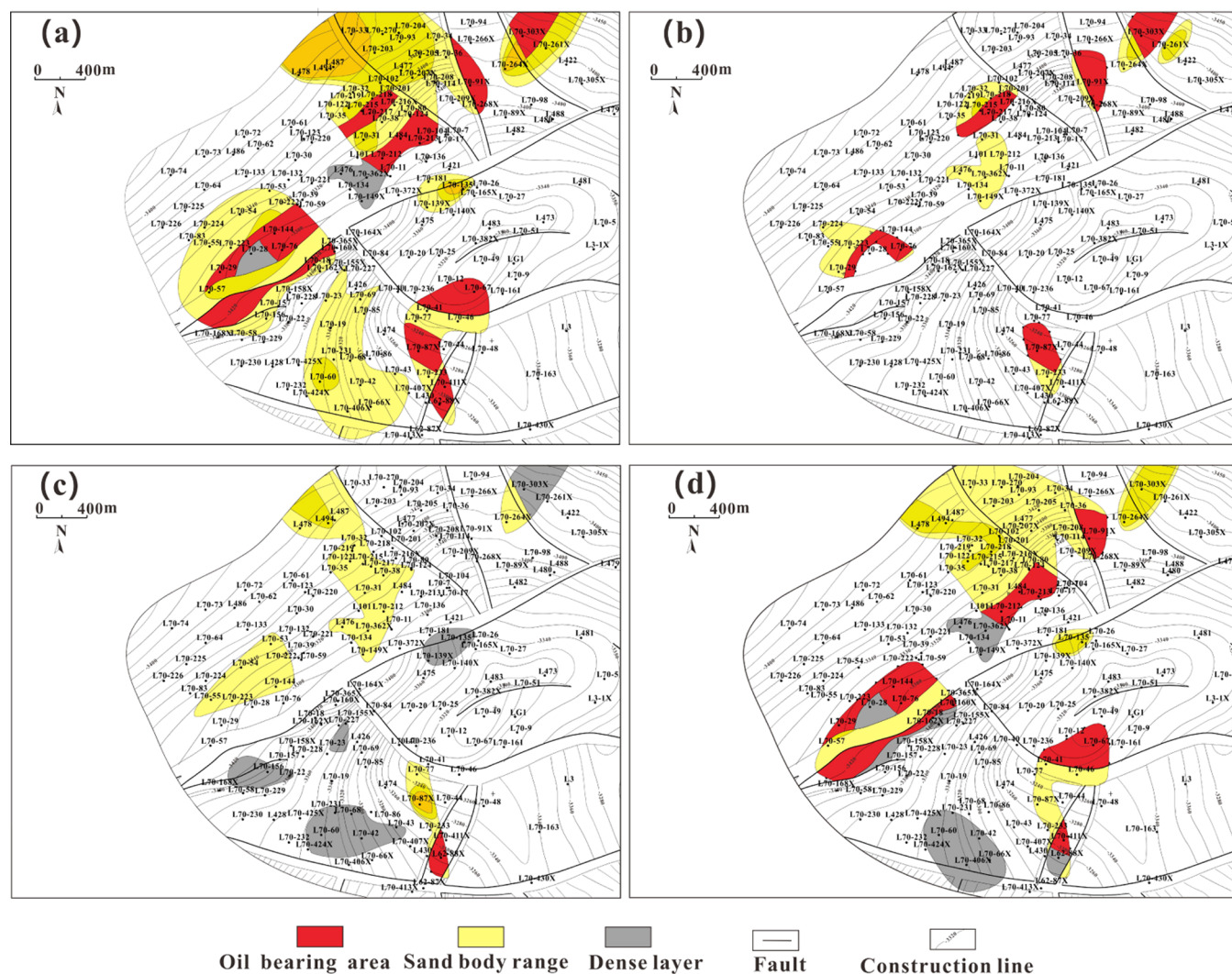
**Figure 12.** $Es_1^L$ I-1 small layer reservoir plan (a) of the L70 fault and single sand layer reservoir unit plans (b−d) of the L70 fault (a: $Es_1^L$ I- 1 small layer reservoir distribution plan; b: $Es_1^L$ I-1-① single sand layer reservoir unit plan; c: $Es_1^L$ I-1-② single sand layer reservoir unit plan; d: $Es_1^L$ I-1-③ single sand layer reservoir unit plan).

single sand body, the sand body in small layer $Es_1^L$ I-1 is generally the product of three-stage river sedimentation. According to the different sedimentation stages of each single sand body, a small layer of $Es_1^L$ I-1 can be divided into $Es_1^L$ I-1-①, $Es_1^L$ I-1-②, and $Es_1^L$ I-1-③ in three sets of single sand layers (Figure 9). As shown in Figure 10, the three sets of single sand layers are separated by argillaceous intercalation facies, which are independent of each other in the longitudinal direction, representing river sediments in different periods.

It is worth noting that the number of single sand layers in different small layers varies due to the different active degrees of river development in the sedimentary period. However, the number of single sand layers in the small layers is not completely determined by the maximum number of single sand bodies in the vertical direction of a single well but the proportion of the number of single sand bodies in the vertical direction of each well section in the small layer.

According to the statistical analysis of the number of single sand bodies developed longitudinally in different well areas of each small layer, the number of single sand bodies under the control of most single wells in each small layer of $Es_1^L$ I oil formation in the study area is only 1−3. Since the number of

single sand bodies developed in different small layers is different, it is also necessary to consider the distribution frequency of the number of single sand bodies controlled by single wells in each small layer of $Es_1^L$ I oil formation (Figure 11). According to the analysis of the distribution frequency diagram of the number of single sand bodies controlled by single wells in each small layer, it can be seen that the $Es_1^L$ I-1 small layer is suitable to be divided into three sets of single sand layers. Although about 80.49% of the single wells in the $Es_1^L$ I-2 small layer develop one to three single sand bodies in the vertical direction, considering that the single sand bodies are not missed in the division of single sand layers, about 19.51% of the single wells develop more than three single sand bodies in the vertical direction. It is finally considered that the $Es_1^L$ I-2 small layer is suitable to be divided into four sets of single sand layers in the vertical direction, and $Es_1^L$ I oil formation in the study area can be divided into seven sets of single sand layers vertically.

Through the study of the lateral connectivity and vertical connectivity of each single sand body of the $Es_1^L$ I oil formation in the study area, the factors affecting the connectivity of sand bodies can be summarized into three
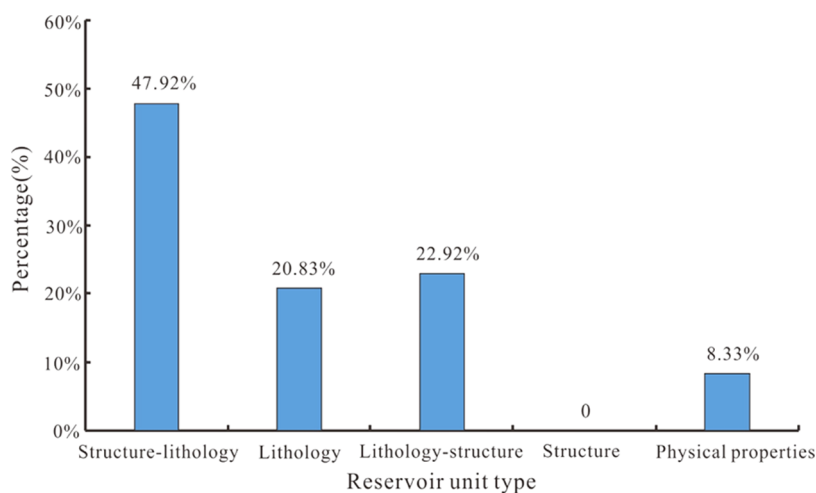
**Figure 13.** Proportional distribution of various reservoir units in $Es_1^L$ I oil formation of the L70 fault block.

types: fault sealing, lithologic sealing, and physical sealing. The accuracy of sand body separation is verified through the combination of dynamic data, which provides an effective guarantee for the later division of reservoir units.

*3.2.3. Classification of Compound Reservoir.* Following the split idea of "body to the surface" for the compound reservoir, the compound reservoir of the $Es_1^L$ I oil formation in the study area is split from "oil formation level" to "small level" and then from small level to "single sand layer level" through the method of stratigraphic division. Based on the oil formation level compound reservoir, through stratigraphic correlation division, the $Es_1^L$ I oil formation reservoir in the study area is divided into two sets of independent and vertically unconnected small level compound reservoirs in the spatial range, taking the $Es_1^L$ I-1 small layer as an example (Figure 12a). In this traditional small level reservoir range, in the same reservoir range, the internal connectivity of the reservoir, whether vertical or horizontal, is extremely fuzzy. The structural reservoir can only be delineated according to the plane structure, but the possible lithologic reservoir cannot be determined. Based on the "small layer" compound reservoir, the connectivity within the reservoir is clarified through the isoelevation comparison of the single sand bodies developed in different sedimentary periods in the small layer. Finally, the two sets of small layer reservoirs in the study area are further divided into seven sets of "single sand layer" reservoirs. In the figure, $Es_1^L$ I-1-①, $Es_1^L$ I-1-②, and $Es_1^L$ I-1-③ are taken as examples (Figure 12b−d).

## 4. RESULTS AND DISCUSSION

**4.1. Reservoir Unit Division Results.** Following the "body to surface" split idea of the compound reservoir, through the conventional small layer division and single sand layer elevation comparison division, the "disassembly" of the $Es_1^L$ I oil formation reservoir in the study area from the oil formation level compound reservoir to single sand layer level compound reservoir is realized. On this basis, according to the guiding ideology of "from surface to point", the single sand-layered compound reservoirs are further divided into the plane according to the connectivity characteristics of sand bodies, and several oil-bearing monomers, i.e., reservoir units, are formed in the spatial range.

According to the lateral connectivity of oil-bearing sand bodies in the plane, the single sand reservoir is divided into several independent reservoir units, and the number statistics of reservoir units in each single sand layer are carried out. The distribution of reservoir units is divided in strict accordance with the distribution law of interpretation conclusion. According to the statistical division results, the composite reservoir of the $Es_1^L$ oil formation is divided into 48 reservoir units, of which the number of reservoir units in each single sand layer is 5, 1, 6, 10, 13, 10, and 3.

**4.2. Types of Reservoir Units and Main Control Factors.** Through the early reservoir unit division, the "disassembly division" from the compound oil-bearing reservoir to the oil-bearing monomer of $Es_1^L$ I oil formation in the study area was realized, and several independent reservoir units in space were formed. According to the classification and statistics of the currently divided reservoir units according to their main control factors in the stratum, they can be divided into "lithologic reservoir unit" (single reservoir closed due to lithologic changes in the plane), "structural reservoir unit" (single reservoir completely closed due to structural control in the plane), and "physical reservoir unit" (single reservoir closed due to the physical property change on the plane is called physical reservoir unit). There are five types of "lithologic structural reservoir unit" (single reservoir formed under the joint control of structural action and lithologic change in the plane, but the structural factor plays a leading role in the formation of the reservoir) and "structural lithologic reservoir unit" (single reservoir formed under the joint control of lithologic change and structural action in the plane, but the lithologic factor plays a leading role in the formation of the reservoir).

According to the statistics of reservoir unit distribution types of each small layer of $Es_1^L$ I oil formation in the study area, it is found that each small layer does not develop a single controlled structural reservoir unit but mainly lithologic reservoir units ("lithologic reservoir units" and "structural lithologic reservoir units"), indicating that the reservoirs in $Es_1^L$ I oil formation in the study area are mainly affected by lithologic factors, structural factors also have a certain impact, followed by physical factors. Through statistical analysis of all reservoir units of $Es_1^L$ I oil formation in the study area, 48 reservoir units are developed in $Es_1^L$ I oil formation in the
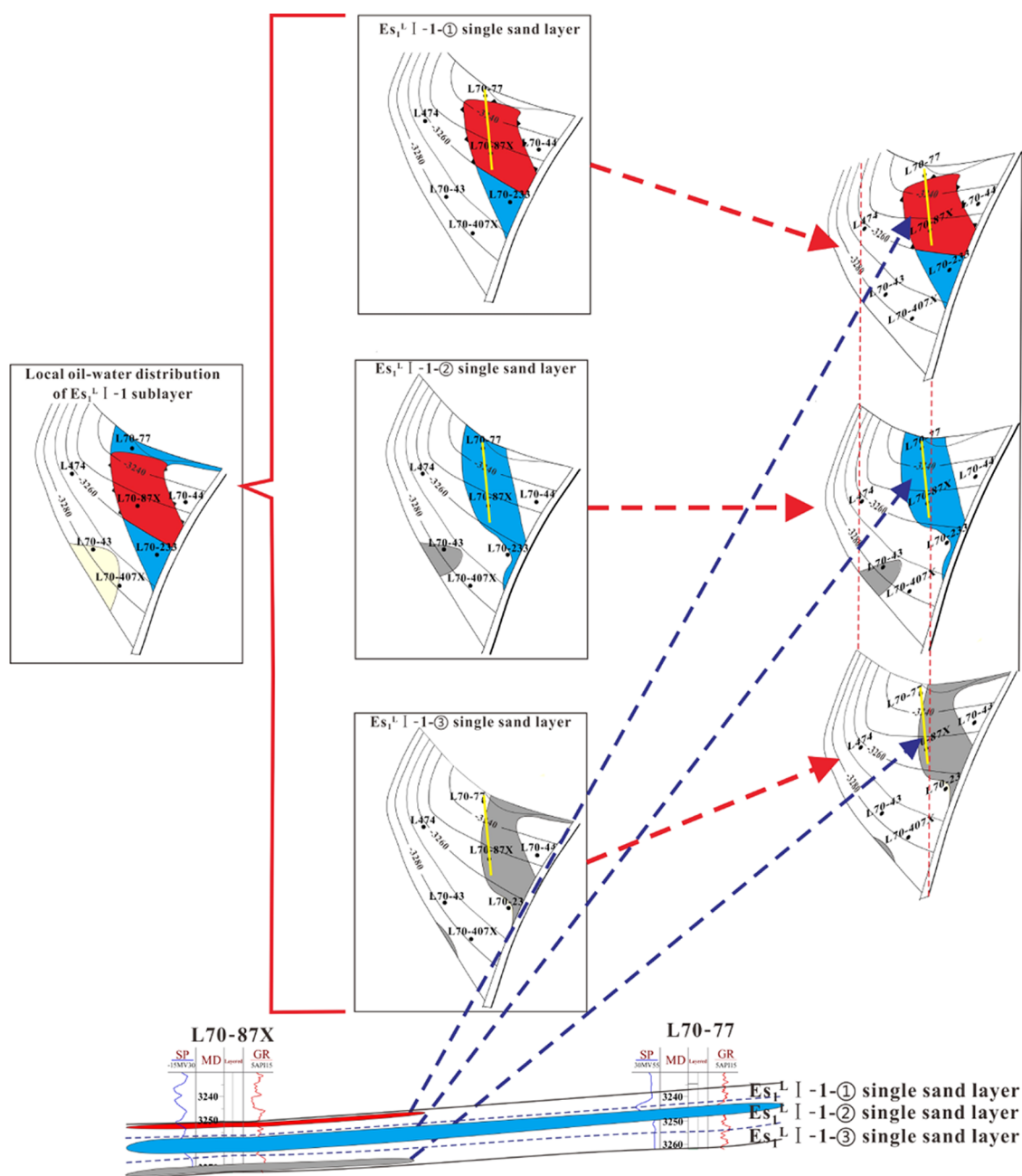
**Figure 14.** Schematic diagram of the oil−water contradiction analysis.

study area, of which lithologic reservoir units account for about 68.75% (Figure 13).

**4.3. Application of Reservoir Units.** The compound reservoir in the study area is divided into reservoir units. The division of reservoir units is of great significance to determine the scope of reservoir and control factors. In the actual production and development process, many practical production problems can be effectively solved by flexibly using the achievements of the reservoir unit division. It is of positive significance for studying the reservoir unit division of Es1L I oil formation, solving the oil−water contradiction in the study area, further improving the rolling exploration and development efficiency of the oil field, and solving the problem of injection production mismatch.

*4.3.1. Clarify the Relationship between Oil and Water and Solve the Contradiction between Oil and Water.* Aiming at

the problem of oil−water inversion in local areas within a small layer, under the theory and research of reservoir unit division, it is found that most of the areas with oil−water contradiction have no actual connection between the high water-bearing sand body and the low oil-bearing sand body, which belong to different single sand layers, are independent of each other, and there is no oil−water contradiction.

As shown in Figure 14, taking the small layer $Es_1^L$ I-1 of well L70-87X−L70-77 in the study area as an example, the plan of the small layer reservoir shows that the high part of well L70-77 contains water and the low part of well L70-87X contains oil, resulting in oil−water inversion. Through the disassembly of the sand body, a small layer of $Es_1^L$ I-1 is divided into three sets of independent single sand layers. It is found that the oil−water distribution in the region is not contradictory. The reason for this phenomenon is that the accuracy of the stratum
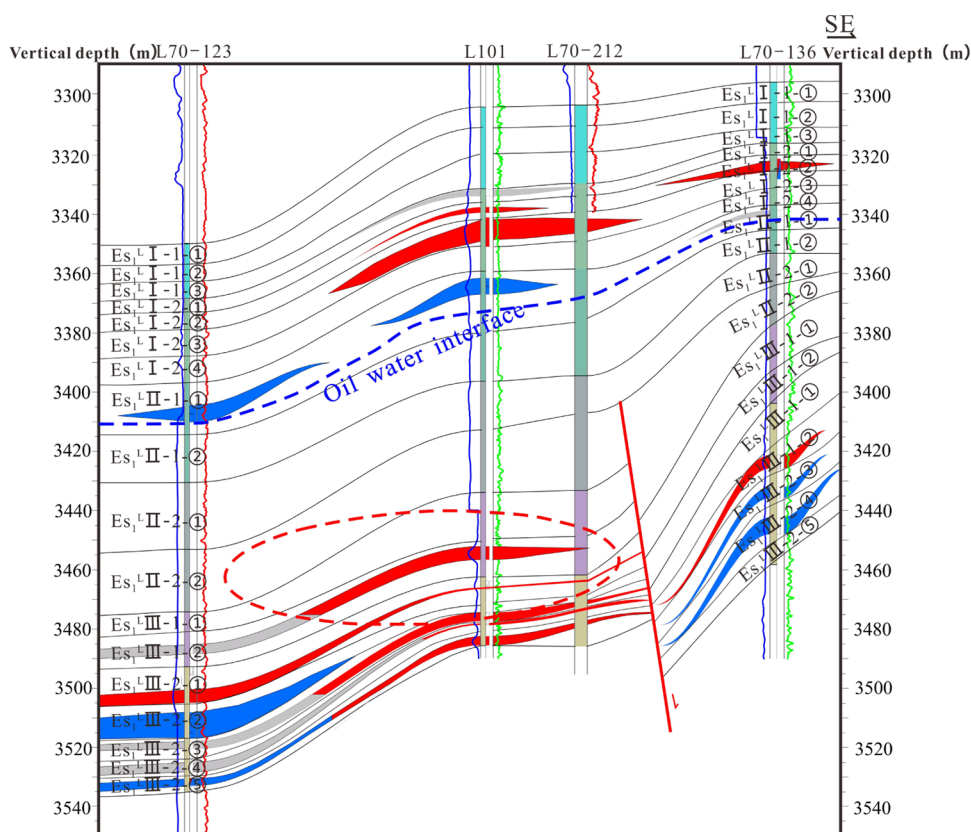
**Figure 15.** Profile of connecting wells in the reservoir.

division is not enough, the plane projection effect is poor, and sand bodies are overlapped. The division of a single sand layer can solve this problem.

*4.3.2. Improve the Effect of Rolling Exploration and Development.* According to the traditional theory of structural reservoir control, the distribution of oil and gas reservoirs is controlled by the structural environment. Under the influence of gravity differentiation, oil and gas usually gather in the high part of the anticline structure, forming a spatial distribution pattern of "upper oil and lower water" in the spatial range. According to the reservoir unit division of the compound reservoir, part of the oil and gas will gather in the low part of the structure in the region due to the influence of lithologic sealing and other factors, forming a lithologic reservoir or lithologic structural reservoir with different sizes and independent of the upper reservoir. Through the guidance of this understanding, we can point out a new direction for future exploration and development, improve the effect of rolling exploration and development, and improve production efficiency.

As shown in Figure 15, the oil−water interface exists in small layer $Es_1^L$II-1 in well L70-123−L101−L70-212−L70-136 in the study area, but reservoir development still exists in $Es_1^L$ III oil formation below the oil−water interface. According to the distribution of such reservoirs, it can be inferred that some low structural parts (such as structural wings) in the study area have great exploration and development potential, which may become a new target for increasing reserves and production.

*4.3.3. Looking for Potential Reservoir Units to Guide the Exploration and Development in This Area.* The volume method is used to calculate the geological reserves of crude oil and dissolved gas. The calculation formula is

$$N = 100A_o h\varphi S_{oi}/B_{oi} \tag{1}$$

$$N_z = N\rho_o \tag{2}$$

where $N$ is the geological reserves of crude oil (volume unit), $10^4$ m$^3$;

$N_z$ is the geological reserves of crude oil (mass unit), $10^4$t;

$A_o$ is the oil-bearing area, km$^2$;

$h$ is the average effective thickness of the oil layer, m;

$\varphi$ is the average effective porosity of the oil layer, f;

$S_{oi}$ is the original oil saturation of the average oil layer, f;

$B_{oi}$ is the volume coefficient of the average formation of crude oil;

$\rho_o$ is the average density of the ground degassed crude oil, g/cm$^3$.

After calculating the geological reserves of each reservoir unit and combining the production data, it is found that $Es_1^L$ I-2-①-5 (L70-48) and $Es_1^L$ I-2-③-7 (L70-48) (Table 2) reservoir units in the study area have great exploration potential, and further development is recommended.

According to the area, effective thickness, porosity, saturation, volume factor, crude oil density, and other data, the geological reserves of each reservoir unit are calculated. Combined with the production data, it is found that the $Es_1^L$ I-2-①-5 (L70-48) and $Es_1^L$ I-2-③-7 (L70-48) (Table 2) reservoir units in the study area have great exploration potential, and further development is recommended.

## 5. CONCLUSIONS

(1) The reservoir unit analysis method theoretically breaks through the shackles of the closed concept in the classical petroleum geological theory, puts forward the

**Table 2. Reservoir Unit Analysis**

| single sand layer | reservoir unit name | type | geological reserves 10$^4$t | representative well | area km$^2$ |
|---|---|---|---|---|---|
| Es$_1^L$I-1-① | Es$_1^L$I-1-①-1 | structural lithologic | 1.7211 | L70-76 | 0.0648 |
| | Es$_1^L$I-1-①-2 | structural lithologic | 3.7226 | L70-215 | 0.0627 |
| | Es$_1^L$I-1-①-3 | structural lithologic | 3.1252 | L70-87L | 0.0762 |
| | Es$_1^L$I-1-①-4 | structural lithologic | 6.5719 | L70-91L | 0.0673 |
| | Es$_1^L$I-1-①-5 | lithologic structural | 7.897 | L70-303L | 0.0832 |
| Es$_1^L$I-1-② | Es$_1^L$I-1-②-1 | structural lithologic | 0.7535 | L62-88L | 0.0371 |
| Es$_1^L$ LI-1-③ | Es$_1^L$I-1-③-1 | lithologic structural | 5.4151 | L70-29 | 0.1631 |
| | Es$_1^L$I-1-③-2 | structural lithologic | 1.2304 | L484 | 0.1125 |
| | Es$_1^L$I-1-③-3 | structural lithologic | 2.3436 | L70-160L | 0.125 |
| | Es$_1^L$I-1-③-4 | structural lithologic | 3.9126 | L70-67 | 0.1318 |
| | Es$_1^L$I-1-③-5 | structural lithologic | 0.465 | L70-411L | 0.0248 |
| | Es$_1^L$I-1-③-6 | structural lithologic | 5.3494 | L70-91L | 0.0646 |
| Es$_1^L$I-2-① | Es$_1^L$I-2-①-1 | physical | 2.253 | L70-62 | 0.0824 |
| | Es$_1^L$I-2-①-2 | physical | 3.8473 | L70-30 | 0.1026 |
| | Es$_1^L$I-2-①-3 | physical | 4.8945 | L70-29 | 0.1053 |
| | Es$_1^L$I-2-①-4 | structural lithologic | 2.0299 | L484 | 0.1052 |
| | Es$_1^L$ I-2-①-5 | lithologic structural | 6.3652 | L70-48 | 0.2037 |
| | Es$_1^L$I-2-①-6 | structural lithologic | 3.7013 | L70-22 | 0.2369 |
| | Es$_1^L$I-2-①-7 | structural lithologic | 3.2981 | L70-43 | 0.1111 |
| | Es$_1^L$I-2-①-8 | structural lithologic | 1.0518 | L70-20 | 0.0561 |
| | Es$_1^L$I-2-①-9 | lithologic structural | 0.8128 | L70-51 | 0.0306 |
| | Es$_1^L$I-2-①-10 | structural lithologic | 0.6037 | L70-26 | 0.0322 |
| Es$_1^L$I-2-② | Es$_1^L$I-2-②-1 | lithologic | 4.1965 | L70-30 | 0.1279 |
| | Es$_1^L$I-2-②-2 | lithologic structural | 5.0493 | L70-59 | 0.0695 |
| | Es$_1^L$I-2-②-3 | structural lithologic | 2.0985 | L70-32 | 0.0407 |
| | Es$_1^L$I-2-②-4 | lithologic structural | 9.2568 | L101 | 0.1703 |
| | Es$_1^L$I-2-②-5 | lithologic structural | 0.4617 | L421 | 0.0197 |
| | Es$_1^L$I-2-②-6 | lithologic | 0.8331 | L70-22 | 0.0172 |
| | Es$_1^L$I-2-②-7 | structural lithologic | 4.1404 | L70-86 | 0.1359 |
| | Es$_1^L$I-2-②-8 | physical | 3.7948 | L426 | 0.2112 |
| | Es$_1^L$I-2-②-9 | structural lithologic | 1.2643 | L70-20 | 0.0476 |
| | Es$_1^L$I-2-②-10 | structural lithologic | 2.2749 | LG1 | 0.0832 |
| | Es$_1^L$I-2-②-11 | structural lithologic | 5.9603 | L70-91L | 0.0561 |
| | Es$_1^L$I-2-②-12 | structural lithologic | 4.5372 | L70-48 | 0.176 |
| | Es$_1^L$I-2-②-13 | lithologic | 2.3142 | L70-39 | 0.0568 |
| Es$_1^L$I-2-③ | Es$_1^L$I-2-③-1 | structural lithologic | 3.9323 | L70-132 | 0.0987 |
| | Es$_1^L$I-2-③-2 | structural lithologic | 11.4562 | L476 | 0.2041 |
| | Es$_1^L$I-2-③-3 | structural lithologic | 4.5237 | L70-58 | 0.0804 |
| | Es$_1^L$I-2-③-4 | structural lithologic | 1.0421 | L426 | 0.0667 |
| | Es$_1^L$I-2-③-5 | structural lithologic | 1.589 | L70-44 | 0.0565 |
| | Es$_1^L$I-2-③-6 | lithologic structural | 1.1906 | L70-411L | 0.0762 |
| | Es$_1^L$I-2-③-7 | structural lithologic | 6.6786 | L70-48 | 0.1943 |
| | Es$_1^L$I-2-③-8 | structural lithologic | 1.2118 | L473 | 0.1108 |
| | Es$_1^L$I-2-③-9 | lithologic | 2.0031 | L70-154L | 0.0662 |
| | Es$_1^L$I-2-③-10 | structural lithologic | 0.4561 | L70-104 | 0.0063 |
| Es$_1^L$I-2-④ | Es$_1^L$I-2-④-1 | structural lithologic | 0.8739 | L70-55 | 0.0799 |
| | Es$_1^L$I-2-④-2 | structural lithologic | 1.9068 | L426 | 0.0452 |
| | Es$_1^L$I-2-④-3 | structural lithologic | 0.4125 | L70-26 | 0.033 |

new concept of reservoir unit, establishes a new method for the study of compound reservoirs with reservoir unit analysis as the core and the division method of four diagrams and four steps, accurately divides reservoir units, and lays a foundation for accurately revealing the genetic mechanism and enrichment law of complex reservoirs.

(2) The reservoir unit can objectively reflect the distribution of underground reserves and solve the contradiction between production and theory. Two potential reservoir units, Es$_1^L$ I-2-①-5 (L70-48) and Es$_1^L$ I-2-③-7 (L70-48),

are proposed in combination with the production practice to prepare for further exploration and development.

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## Notes

The authors declare no competing financial interest.

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