



Characteristics and Oil Control Effect of Chang 8₁ Tight Reservoir in W105 Area of Nanliang Oilfield, Ordos Basin

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Abstract

The research on the main controlling factors of tight oil has always been the core content of unconventional oil and gas geology theory. Taking the tight oil of Chang 8₁ reservoir group in W105 area of Nanliang Oilfield in Ordos Basin as the research object, the characteristics of reservoir sand body thickness, lithology, reservoir space and physical properties were analyzed by using logging, mud logging, core and oil test data. The type of Chang 8₁ reservoir was clarified, and the control effect of reservoir properties on Chang 8₁ tight oil was revealed. The results show that the average thickness of Chang 8₁ sand body in W105 area of Nanliang oilfield is 3.2 m. The reservoir lithology is mainly composed of fine-grained lithic feldspar sandstone and feldspar lithic sandstone. The reservoir space types of Chang 8₁ are mainly intergranular pores and feldspar dissolved pores. The average porosity of the reservoir is 8.7%, and the average permeability is 0.28 mD, which belongs to the tight reservoir. Chang 8₁ reservoir type is lithologic reservoir. Summary: When the sand body thickness of Chang 8₁ tight oil is greater than 5 m and the shale content is less than 15%, it is a fine sandstone with good physical properties, which is conducive to the formation of tight oil enrichment and high yield.

Subject Areas

Geography

Keywords

Ordos Basin, Nanliang Oilfield, Chang 8₁ Member, Tight Oil

1. Introduction

With the depletion of conventional oil and gas exploration and development, unconventional oil and gas exploration and development has become the main development direction to increase oil and gas reserves and production. Tight oil reservoirs are one of the important unconventional oil and gas reservoirs. Tight oil reservoirs in China are mainly concentrated in the Cretaceous Qingshankou Formation in Songliao Basin [1] [2], Jurassic Da'anhai Formation in Sichuan Basin, Triassic Yanchang Formation in Ordos Basin and Permian Lucaogou Formation in Junggar Basin [3] [4]. The Ordos Basin is the second largest sedimentary basin in China, with an area of about $25 \times 10^4 \text{ km}^2$ [5]. It is also one of the basins with the most abundant tight oil resources in China. The tight oil resources in the basin account for about a quarter of the total amount in China. The southwestern part of the basin spans the two tectonic units of Tianhuan Depression and Yishan Slope in geological structure, and the content of oil and gas resources is abundant [6] [7]. The Triassic Yanchang Formation in the Ordos Basin is rich in oil and gas resources. Its Chang 7 develops black shale, which is adjacent to the underlying Chang 8 formation. The oil and gas can migrate to the Chang 8 sandstone in a short distance, forming a tight reservoir of "upper generation and lower storage" [8] [9].

The Mesozoic in Ordos Basin is the main layer of oil exploration, which has the characteristics of many oil-bearing strata and wide distribution area [10]. Especially in Jiyuan, Xifeng, Qingyang and Xin'anbian, the tight oil reservoirs dominated by Chang 3, Chang 6 and Chang 7 were found. With the continuous exploration and development, the horizon above the main source rocks of Chang 7 has entered the middle and late stages of development, and the exploration horizon has gradually extended vertically. The Chang 8 oil layer group adjacent to the source rock has the characteristics of sufficient oil source and favorable reservoir forming conditions, and has become the main layer system for increasing oil reserves and production [11].

2. Geological Background of the Study Area

The W105 area of the Nanliang Oilfield is located in Zhidan County and Jingbian County, Shaanxi Province. It is structurally located in the southwestern part of the northern Shaanxi slope of the Ordos Basin. The study area is about 95 km^2 (see **Figure 1(a)**). The Triassic Yanchang Formation and Fuxian Formation, Jurassic Yan'an Formation, Zhiluo Formation, Anding Formation and Luohe Formation are developed in Nanliang Oilfield. Among them, the Yanchang Formation is fully developed, from the lower Chang 10 oil layer to the top Chang 1 oil layer [12]. The thickness of Chang 8₁ oil layer group is 40 - 56 m. By using the method of marker layer and thickness control, Chang 8₁ is subdivided into two sets of small layers, namely, Chang 8₁¹ small layer and Chang 8₁² small layer, and Chang 8₁² small layer is subdivided into Chang 8₁²⁻¹ small layer, Chang 8₁²⁻² small layer and Chang 8₁²⁻³ small layer. The Chang 8₁ structure is generally characterized by a west-

dipping monocline of “high in the east and low in the west”, and the nose structure is locally developed. The structure of each small layer is inherited vertically (see **Figure 1(b)**). The braided river delta front sedimentary system is developed in Chang 8₁ of Yanchang Formation in the whole basin. The sedimentary microfacies can be divided into underwater distributary channel, underwater natural levee and interdistributary bay. Turbidite channel microfacies are mainly developed, which are favorable reservoirs. Because the Chang 8₁ section of the western Nanliang area has the ability to generate oil and is adjacent to the Chang 7 source rock series, it can form a self-generating and self-storing oil-forming combination [13]. At the same time, the thick carbonaceous mudstone and mudstone of the Chang 7 section provide a good cap rock for the Chang 8₁ reservoir. Therefore, the Chang 8₁ reservoir in the Nanliang oilfield has a solid foundation as a high-quality reservoir.

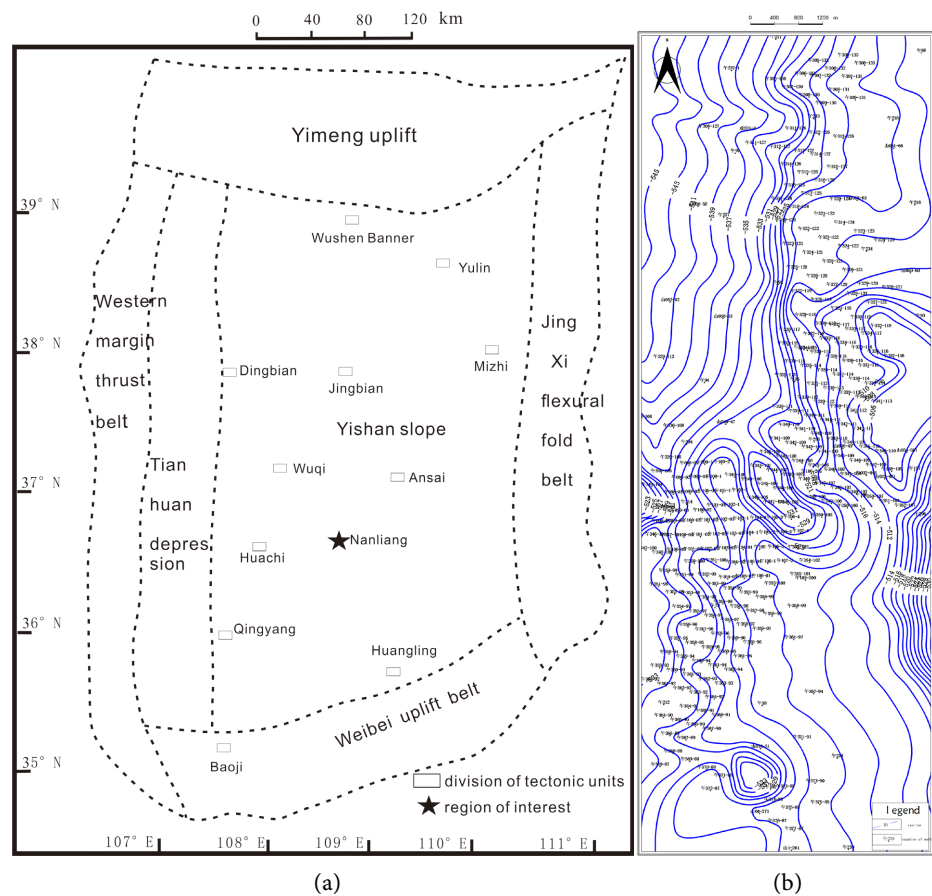


Figure 1. Location map of Nanliang area in Ordos Basin and isoline map of Chang 8 top structure in W105 area. (a) Location map of Nanliang area; (b) The isoline map of Chang 8 top structure in W105 area.

3. Chang 8₁ Reservoir Conditions

3.1. Reservoir Sand Body Thickness

The braided river delta front sedimentary system is developed in Chang 8₁ reser-

voir of W105 area in Nanliang oilfield. The sand bodies are mainly underwater distributary channel microfacies, underwater natural levee microfacies and inter-distributary bay microfacies. On the logging curve, it shows the response characteristics of low natural gamma, high natural potential negative anomaly and high acoustic time difference. The curve shape is mainly bell-shaped, box-shaped, and rarely funnel-shaped. Sand bodies are widely developed in the whole area, and block bedding, cross bedding and parallel bedding can be seen on the core (see **Figure 2**).

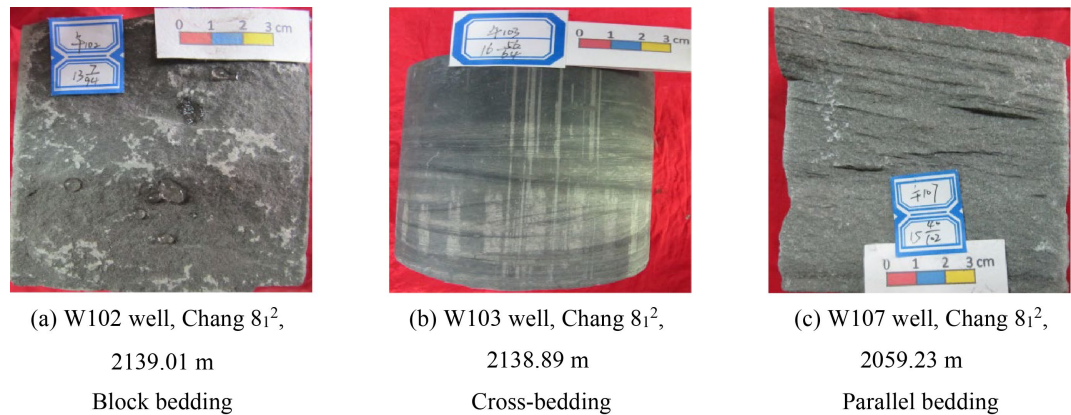
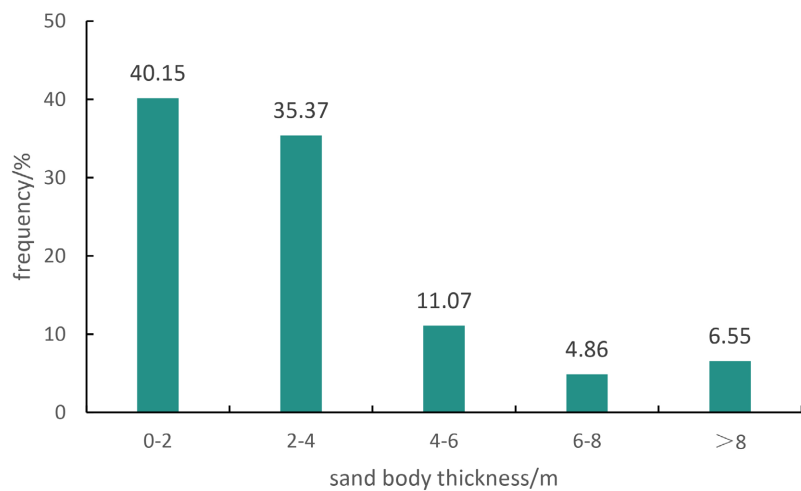


Figure 2. Core observation of Chang 8₁ in Nanliang W105 area, Ordos Basin.

Through the statistics of channel sand body, the thickness of Chang 8₁ sand body is 0.1 - 19.7 m, and the average thickness is 3.2 m. Among them, the thickness of Chang 8₁¹ sand body is 0.1 - 19.7 m, the average thickness is 3.1 m, and the sand body with thickness of less than 4m accounts for 75.52% of the total sand body (see **Figure 3(a)**). The thickness of the Chang 8₁² sand body is 0.1 - 18.3 m, with an average thickness of 3.3 m. The sand bodies with a thickness of less than 4 m account for 70.74% of the total number of sand bodies (see **Figure 3(b)**).



(a)

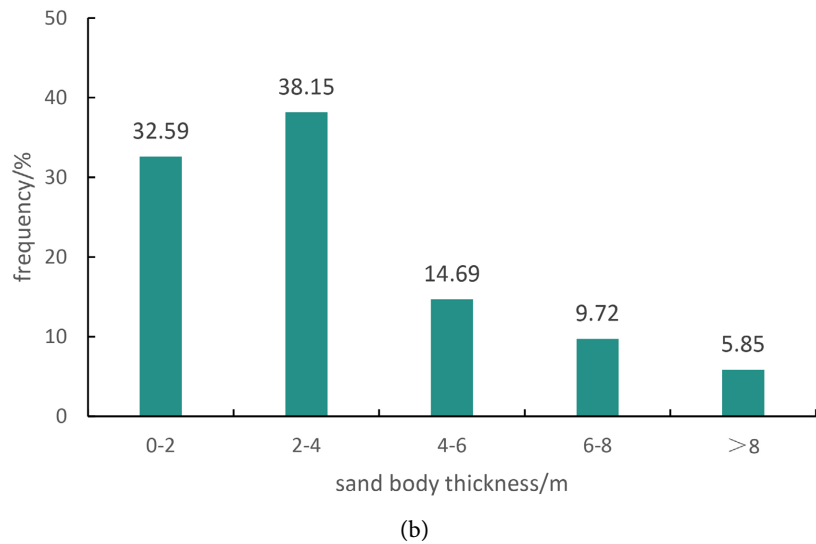


Figure 3. Histogram of Chang 8₁ sand body distribution in W105 area of Nanliang, Ordos Basin. (a) Chang 8₁¹; (b) Chang 8₁².

3.2. Reservoir Petrological Characteristics and Pore Structure

3.2.1. Reservoir Petrological Characteristics

The lithology of Chang 8₁ reservoir in W105 area of Nanliang oilfield is mainly composed of fine-grained lithic feldspar sandstone and feldspar lithic sandstone (see **Figure 4**). Among them, the quartz content of Chang 8₁¹ is 22% - 39%, with an average of 30.27%. The content of feldspar ranges from 11.5% to 34%, with an average of 27.15%. The rock debris content is 15% - 34.8%, with an average of 26.74%. Rock debris types include metamorphic rock debris, volcanic rock debris and mica. The quartz content of Chang 8₁² is 21.5% - 40%, with an average of 34.38%. The content of feldspar ranges from 23% to 36%, with an average of 30.92%. The debris content is 15% - 39.7%, with an average of 22.52% (see **Figure 5**).

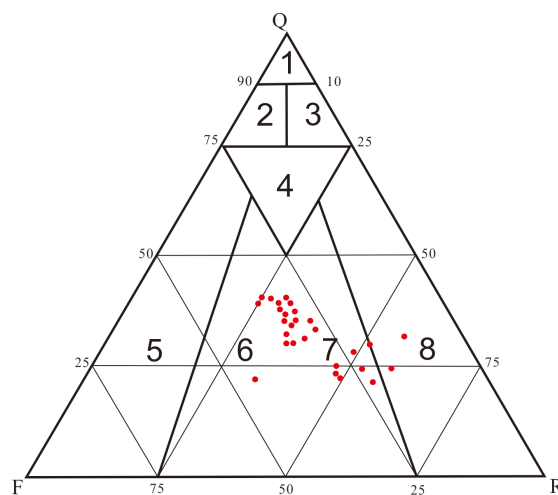


Figure 4. Lithology triangle diagram of Chang 8₁ reservoir in Nanliang W105 area, Ordos Basin.

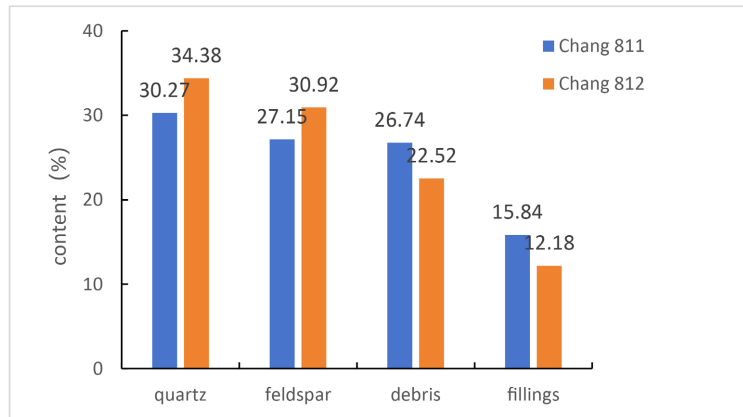


Figure 5. Columnar diagram of rock mineral composition in Nanliang W105 Chang 8₁ area, Ordos Basin.

3.2.2. Characteristics of Reservoir Interstitial Material

Through 10 coring wells, 18 casting thin section statistics and scanning electron microscope analysis, it is concluded that the interstitial content of sandstone in Chang 8₁ reservoir group in the study area is about 4% - 32%, with an average of 12.5%. The types of interstitial materials are relatively single, mainly authigenic clay minerals and carbonate cements, and clay minerals are mainly chlorite and illite. Carbonate cements are mainly ferrocalcite. In addition, there is a certain amount of siliceous and a small amount of feldspar. The content of interstitial material in Chang 8₁¹ sandstone is 15.84%, of which illite accounts for 5.93%, chlorite accounts for 0.33%, ferrocalcite accounts for 6.28%, siliceous accounts for 2.38%, feldspar accounts for 0.5%, and others are a small amount of reticular clay. The content of interstitial material in Chang 8₁² sandstone is 12.18%, of which illite accounts for 0.93%, chlorite accounts for 2.88%, ferrocalcite accounts for 5.54%, siliceous accounts for 2.54%, feldspar accounts for 0.36%, and others are a small amount of reticular clay (see Figure 6).

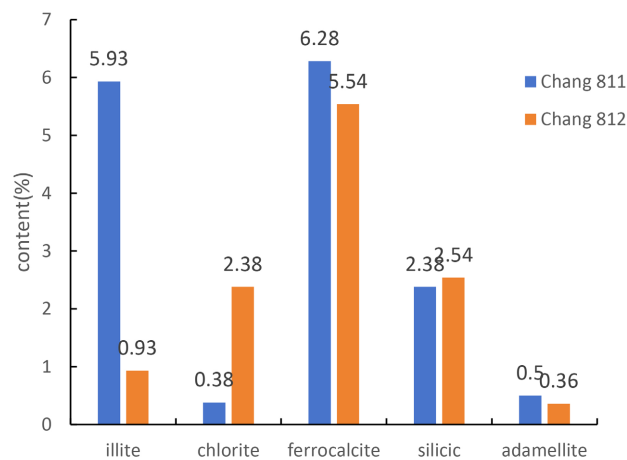


Figure 6. Chang 8₁ interstitial content distribution map of Nanliang W105 area in Ordos Basin.

The development of illite and iron calcite mainly plays a destructive role in the reservoir, which reduces the porosity and permeability of the reservoir to a certain extent [11]. Higher siliceous content indicates that the space of intergranular pores is larger during sediment deposition, and the content of clay minerals attached to the surface of the particles is relatively small, so it is conducive to siliceous hyperplasia [14]. Siliceous and feldspar mainly exist in the form of quartz, feldspar authigenic enlarged edge and authigenic quartz and albite growing in pore space. The appearance of chlorite has a certain destructive effect on intergranular pores, but the appearance of early chlorite film also plays a constructive role in the preservation of primary pores [15] (see **Figure 7**).

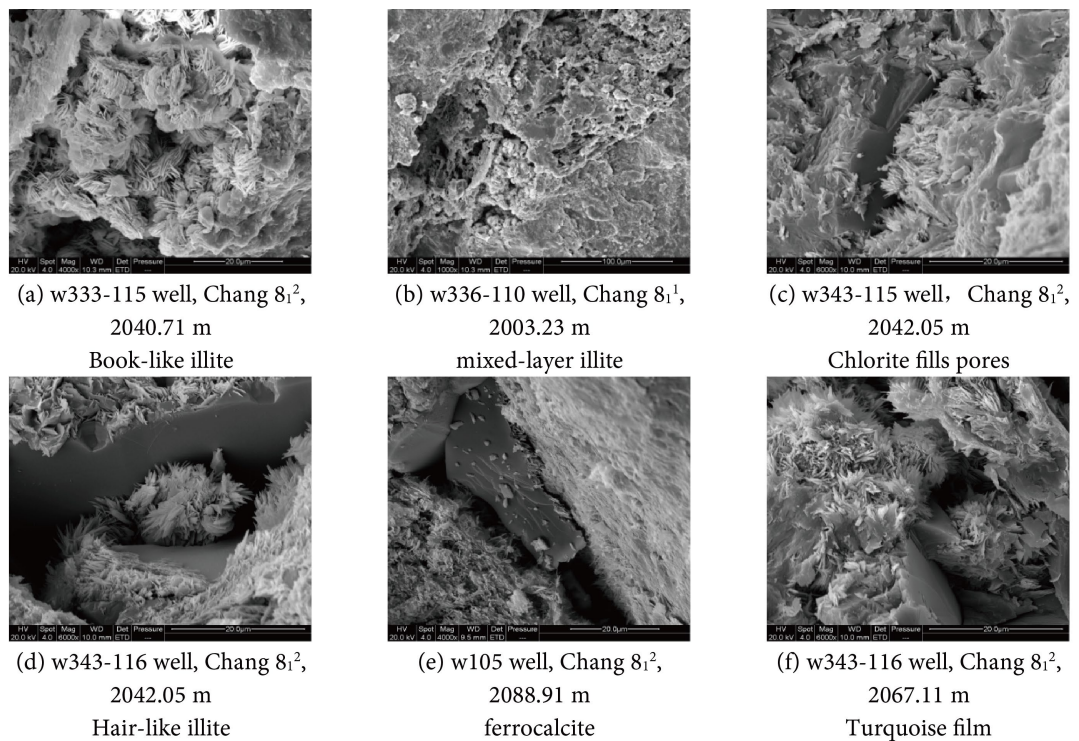


Figure 7. Clay minerals of Chang 8₁ in Nanliang W105 area, Ordos Basin.

3.2.3. Types of Reservoir Space

Affected by compaction, dissolution, cementation and fracture, the reservoir space types of Chang 8₁ reservoir mainly include intergranular pores and feldspar dissolved pores. Feldspar dissolution pores are the main reservoir space in the study area, and their development is the highest in the study area. Their formation is often limited by cleavage and metasomatic minerals. They are dissolved along cleavage and fissures, and the shape is network or irregular intragranular dissolution pores [16]. The remaining pores after compaction and filling cementation have the highest degree of development in this area, with triangles, polygons, and irregular shapes [17]. The distribution of lithic dissolved pores and microcracks in this area is limited, and the pore size is large. They contribute greatly to the pore properties of reservoir sandstone.

3.3. Reservoir Physical Characteristics

By analyzing the porosity and permeability of Chang 8₁ reservoir in W105 area of Nanliang Oilfield, the overall porosity of the reservoir is 1.5% - 17.2% (N = 236), with an average of 8.7% and a median of 7.3%. The porosity is 6% - 9%, accounting for 45.2% of the total number of samples. The permeability is 0.05 - 8.94 mD (N = 236), the average is 0.28 mD, the median is 0.23 mD, and the permeability is mainly 0.1 - 0.3 mD, accounting for 69.3% of the total number of samples. The porosity and permeability of Chang 8₁ reservoir are positively correlated. With the increase in porosity, the permeability also shows an increasing trend. The porosity of Chang 8₁¹ is lower than that of Chang 8₁², and the permeability is equivalent. The porosity of Chang 8₁¹ is 1.5% - 16.8% (N = 106), with an average of 5.93% and a median of 6.05%. The main porosity is 4% - 6%, accounting for 26.7% of the total number of samples (see Figure 8(a)). The permeability is 0.05 - 7.29 mD (N = 106), the average is 0.29 mD, the median is 0.24 mD, and the permeability is 0.1 - 0.3 mD, accounting for 49.6% of the total number of samples (see Figure 8(b)). The porosity of Chang 8₁² is 1.5% - 17.2% (N = 130), with an average of 6.09% and a median of 5.85%. The main body of porosity is 4% - 6%, accounting for 27.5% of the

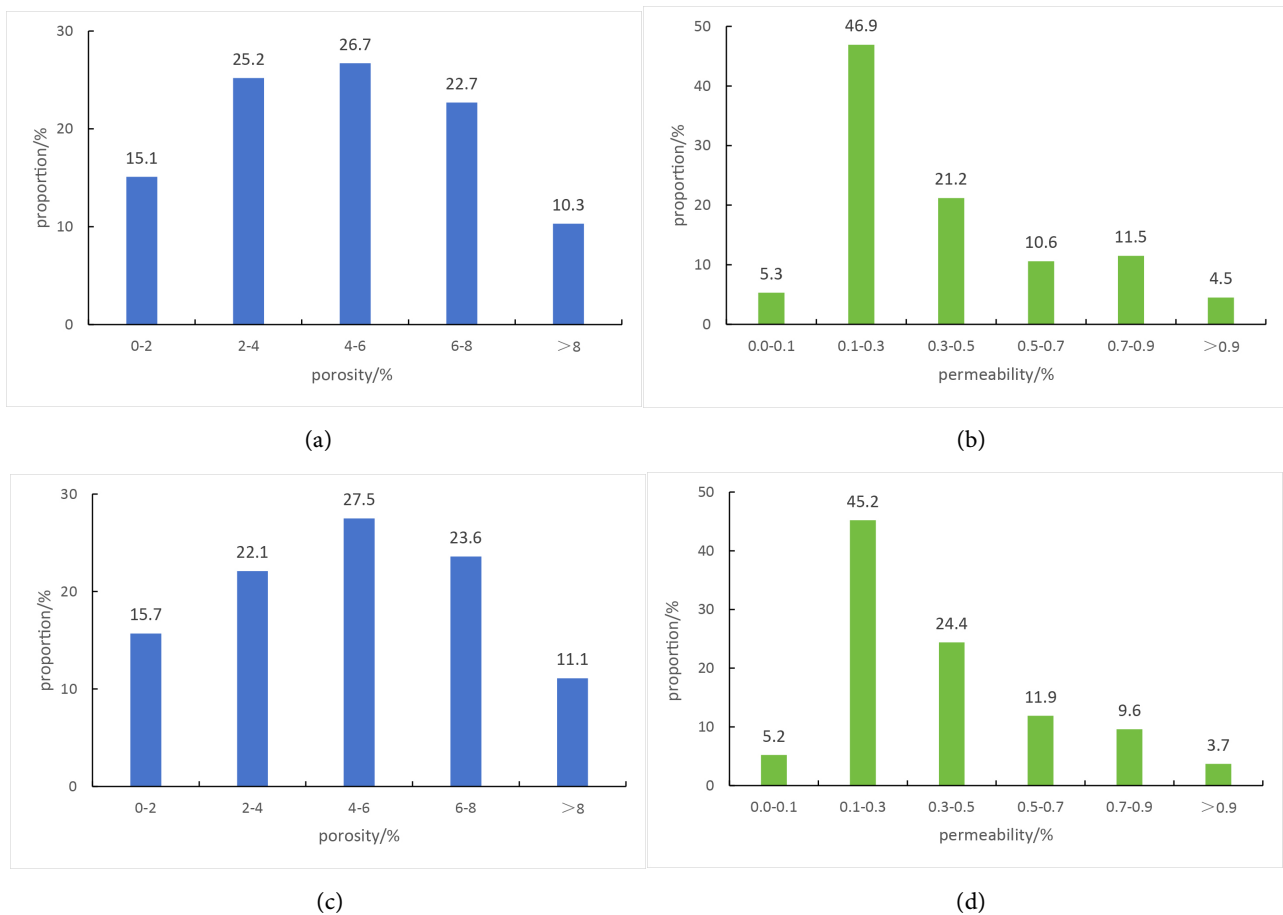


Figure 8. Histogram of Chang 8₁ porosity and permeability distribution in Nanliang W105 area, Ordos Basin. (a) Chang 8₁¹ porosity; (b) Chang 8₁¹ permeability; (c) Chang 8₁² porosity; (d) Chang 8₁² permeability.

total number of samples (see **Figure 8(c)**). The permeability is 0.05 - 4.53 mD ($N = 130$), the average is 0.27 mD, the median is 0.23 mD, and the permeability is mainly 0.1 - 0.3 mD, accounting for 45.2 % of the total number of samples (see **Figure 8(d)**). The Chang 8_1 reservoir in the study area can be classified as low porosity-extra low permeability reservoir, which belongs to tight reservoir [18].

4. Chang 8 Reservoir Characteristics

4.1. Oil Layer Distribution

According to the statistics of oil test results of 236 layers of Chang 8_1 reservoir in W105 area of Nanliang oilfield, the industrial oil layer (>2 t/d) and low production oil layer (0.5 - 2 t/d) are 95 layers and 44 layers respectively, accounting for 48.2% of the total test oil layer. The oil display layer and water layer are 51 and 60 layers, respectively, accounting for 38.6% of the total oil layer. The oil production in the test results is 0.00 - 8.56 t/d, with an average of 1.25 t/d, and the water production is 0 - 29 t/d, with an average of 4.23 t/d. The proportion of oil layers produced by Chang 8_1^{2-1} and Chang 8_1^{2-2} is much higher than that of Chang 8_1^1 and Chang 8_1^{2-3} . There are 197 layers in Chang 8_1^2 test oil layer, including 77 layers of industrial oil layer and 28 layers of low production oil layer, accounting for 53.3% of the total test oil layer, which are distributed in the whole study area. There are 72 layers in the test oil layer of Chang 8_1^1 , including 18 industrial oil layers and 16 low-yield oil layers, accounting for 47.2% of the total test oil layers, which are only distributed in the southern part of the study area.

4.2. Reservoir Type

The Nanliang area is located in the southwestern part of the Ordos Basin. During the sedimentary period of Chang 8_1 in the Ordos Basin, shallow water delta and lake sedimentary facies were mainly developed. The Chang 8_1 in the study area mainly developed braided river delta front sedimentary system. The delta front is the main part of the delta deposition, which is the underwater deposition of the delta distributary channel into the lake basin. It is located in the coastal shallow water gentle slope zone below the estuary. It is the river-lake interaction zone and the development area of sand layer concentration. The delta front subfacies in the study area can be subdivided into three microfacies: underwater distributary channel, underwater natural levee and interdistributary bay. The type of Chang 8_1 reservoir in the study area is lithologic reservoir [19]. The lithologic pinch-out of adjacent source rocks and sandstones is the basic condition for the formation of lithologic reservoirs. The oil and gas of Chang 8_1 reservoir group mainly come from the underlying Chang 7 source rock, and the oil and gas accumulate in the appropriate sand body trap. It is found that the distribution of oil and gas is obviously controlled by the distribution of sand body, and the oil layer is continuous (see **Figure 9** and **Figure 10**).

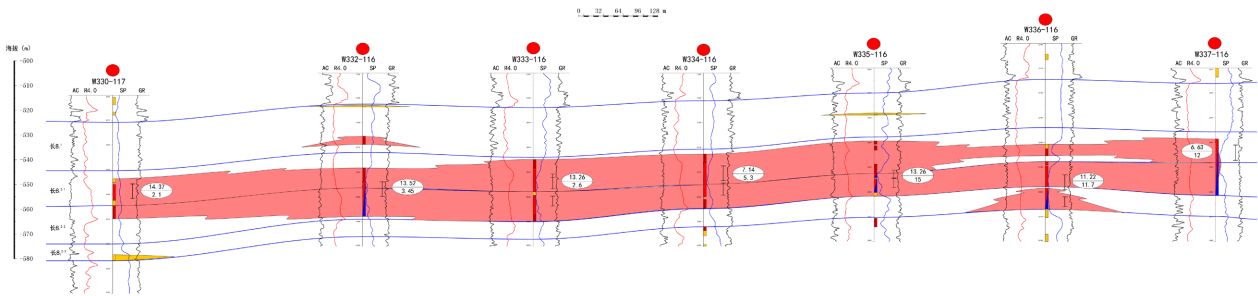


Figure 9. Profile of Chang 8₁ reservoir in Nanliang W105 area of Ordos Basin (along the source).

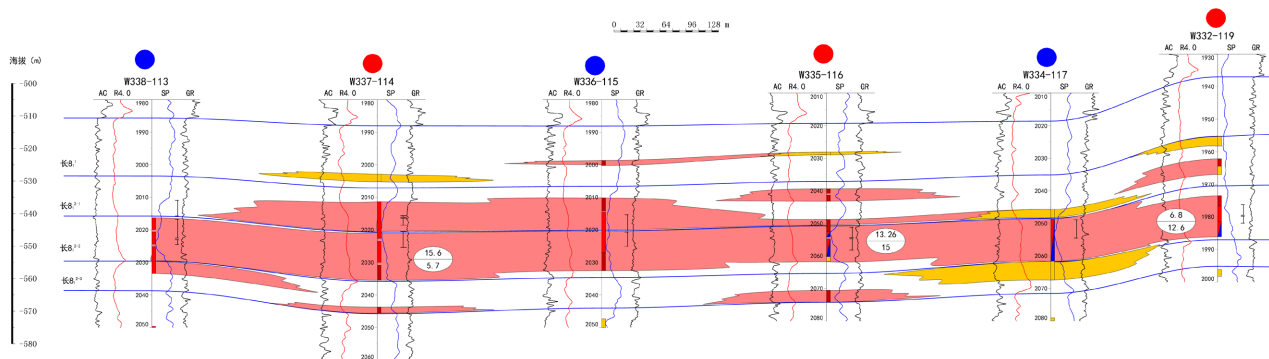


Figure 10. Profile of Chang 8₁ reservoir in Nanliang W105 area of Ordos Basin (cutting source).

5. The Control Effect of Chang 8 Reservoir on Oil Pool

5.1. Controls on Oil Accumulation of Reservoir Sand Body

Through the statistics of oil production, water production and perforation single sand body thickness and shale content of Chang 8 industrial oil layer and low production oil layer, the sand body is distributed in 1.6 - 14.8 m, with an average of 5.8m; the shale content of the sand body is 9.8 - 42.7%, with an average of 16.2%. With the increase in sand body thickness, the oil production of Chang 8₁¹ and Chang 8₁² has an increasing trend. When the thickness of sand body exceeds 5m, it is easy to form industrial oil layer (see Figure 11(a)). The thickness of sand body and water production show a decreasing trend. With the increase of sand body thickness, the water production of Chang 8₁¹ and Chang 8₁² decreases obviously (see Figure 11(b)). With the increase of mud content, the oil production of Chang 8₁¹ and Chang 8₁² decreased significantly (see Figure 11(c)). The relationship between the shale content of the sand body and the daily water production generally shows a positive correlation trend; that is, with the increase of the shale content of the sandstone, the water production of Chang 8₁¹ and Chang 8₁² has an increasing trend (see Figure 11(d)).

5.2. Controls on Oil Accumulation of Reservoir Lithology

Through core observation, combined with the results of Chang 8₁ oil test in W105 area of Nanliang Oilfield, it is known that the oil layers are concentrated in fine

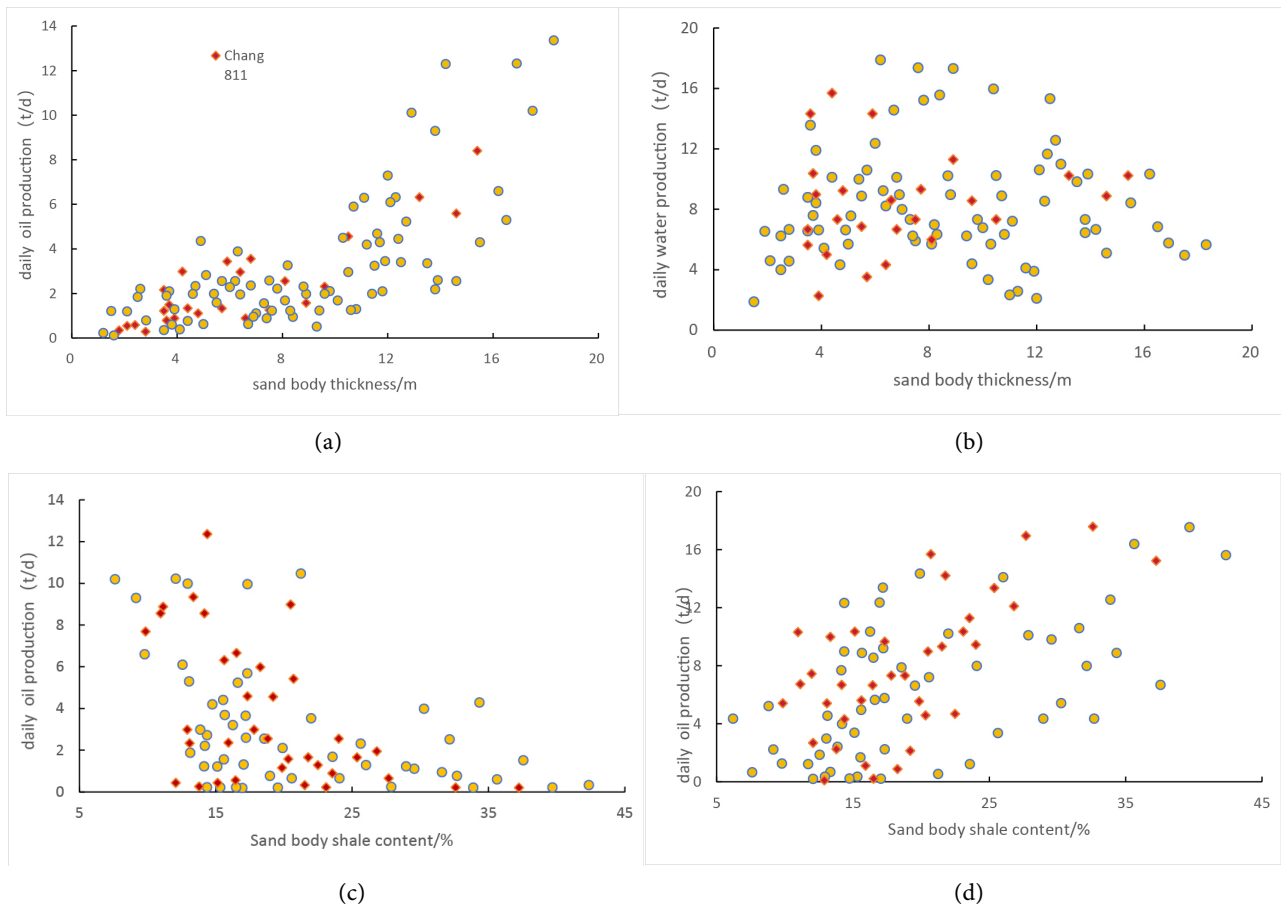


Figure 11. Intersection diagram of Chang 8₁ sand body thickness, sand body shale content and oil test results in Nanliang W105 area of Ordos Basin. (a) Sand body thickness-daily oil production; (b) Sand body thickness-daily water production; (c) Sand body shale content-daily oil production; (d) Sand body shale content-daily water production.

sandstone and siltstone. It can be seen from the statistics of lithologic oil-bearing levels of different grain sizes that as the grain size of the lithology gradually becomes finer, the oil-bearing property gradually becomes worse (see **Figure 12**). The oil-bearing grade of fine sandstone is the highest, and the oil spots and oil marks are 16.8 m and 47.3 m respectively, accounting for 65.3% of the length of fine sandstone. Followed by siltstone, oil spots and oil marks were 7.8 m and 15.3 m, accounting for 25.3% of the length of siltstone; for argillaceous siltstone, only oil trace is 10.3 m, accounting for 13.4% of argillaceous siltstone, and the rest is fluorescence and no display oil level. The mudstone is fluorescent and shows no oil level. These show that the reservoir lithology has obvious control effect on the distribution of the oil layer and the oil content of the core.

5.3. Controls on Oil Accumulation of Reservoir Physical Properties

Through the statistics of oil-bearing grade of cores with different physical properties, with the increase of reservoir porosity and permeability, the oil-bearing grade of cores gradually becomes better (see **Figure 13**). In different porosity

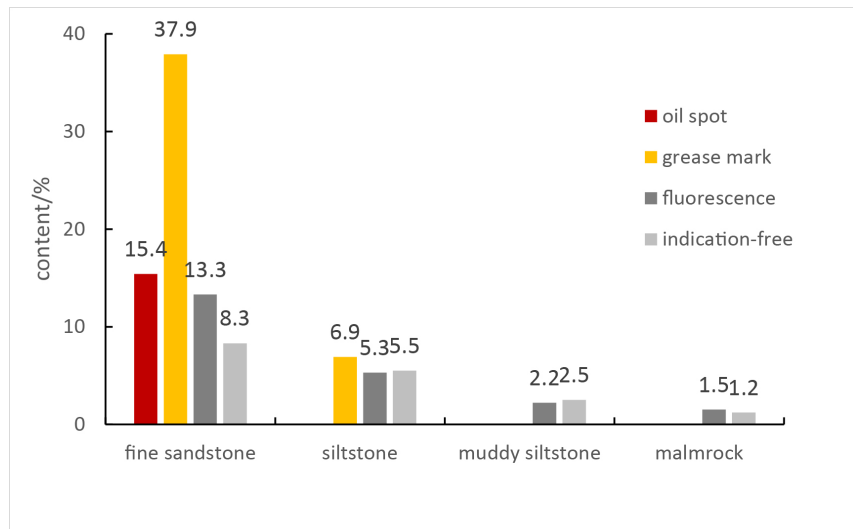


Figure 12. Histogram of oil-bearing grade of Chang 8₁ lithology in Nanliang W105 area, Ordos Basin.

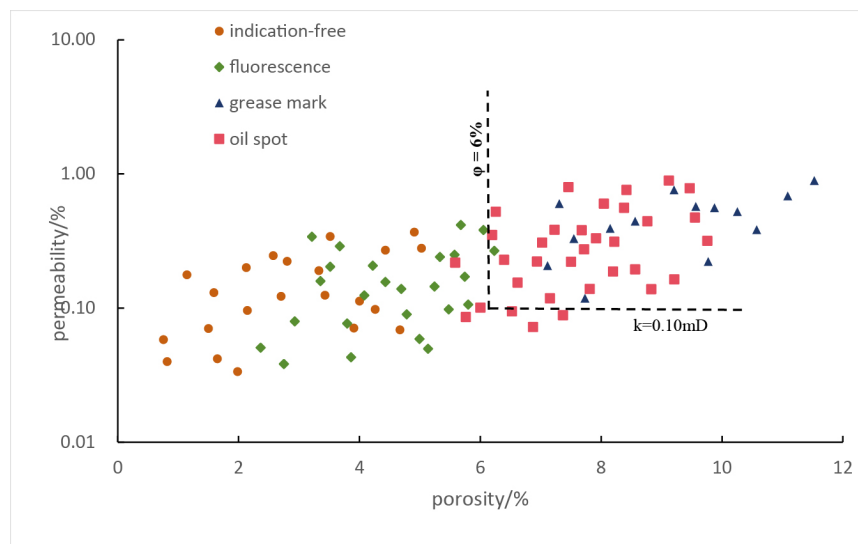


Figure 13. The relationship between physical properties and oil-bearing property of Chang 8₁ in Nanliang W105 area, Ordos Basin.

intervals, the oil-bearing level is different. When the porosity is greater than 9%, the oil level is mainly oil stains and oil spots. When the porosity is 6% - 9%, the oil-bearing grade is mainly fluorescence; when the porosity is less than 6%, mainly for no display oil level. With the increase of permeability, the oil grade shows a slight increasing trend, but the degree of change is weaker than the influence of porosity. Roughly when the permeability is greater than 0.1mD, the proportion of oil spots and oil traces increases significantly.

The porosity and permeability of Chang 8₁ industrial oil layer and low-yield oil layer are counted (N = 18). With the increase of reservoir porosity and permeability, the daily production has a more obvious increasing trend (see Figure 14). With the increase of porosity, the high value envelope of daily oil production in-

creases obviously, especially when the porosity is greater than 9%, it is easy to form high-yield oil layer. As the permeability increases, the high-value envelope of oil production increases significantly. When the permeability is greater than 0.4 mD, it is easy to form high-yield oil layers.

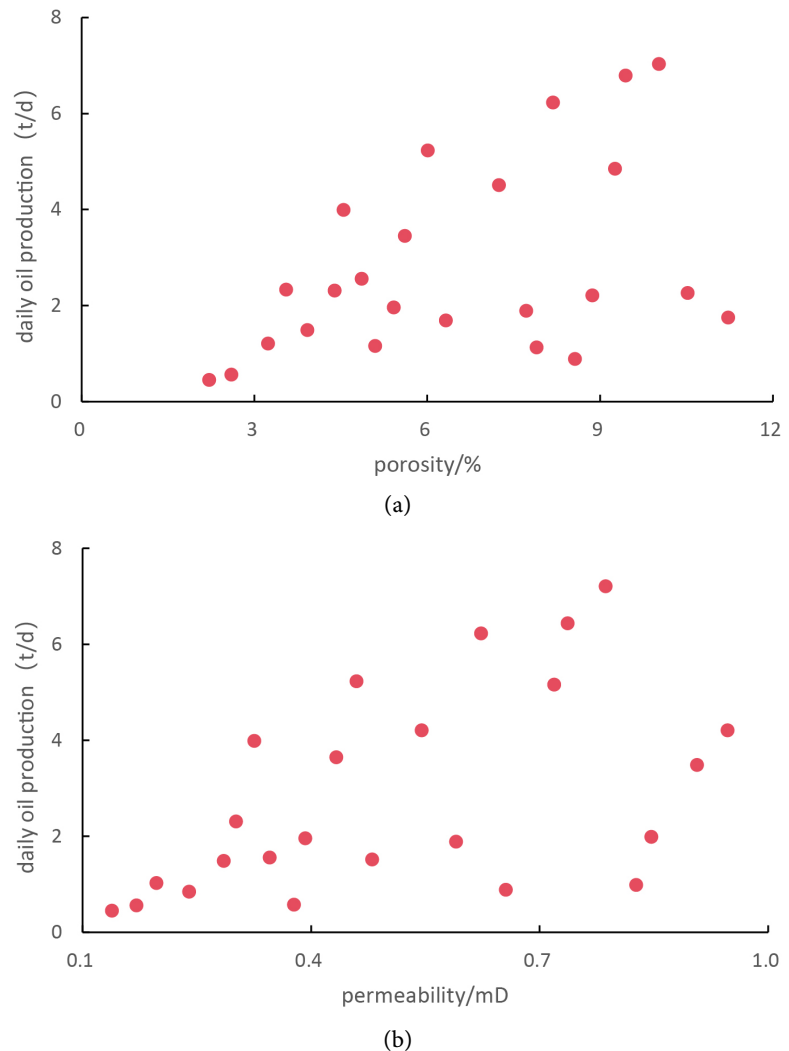


Figure 14. Intersection diagram of physical properties and oil test results of Chang 8₁ in Nanliang W105 area of Ordos Basin. (a) Daily oil production- porosity; (b) Daily oil production-permeability.

6. Conclusions

1) The lithology of Chang 8₁ reservoir in W105 area of Nanliang oilfield is mainly composed of fine-grained lithic feldspar sandstone and feldspar lithic sandstone. The reservoir space types mainly include intergranular pores and feldspar dissolved pores. The average porosity is 8.7% and the average permeability is 0.28 mD, which belongs to tight reservoir.

2) Chang 8₁ in the study area is dominated by delta front deposits, mainly developing underwater distributary channel microfacies and interdistributary bay mi-

crofacies. Chang 8₁² is the main formation, sand body development is good, the average thickness is 3.1m, sand body connectivity is good, and the scale is large, which is conducive to oil and gas reservoirs. The study found that the distribution of oil and gas is obviously controlled by the distribution of sand bodies. Chang 8₁ in the study area is a lithologic reservoir.

3) The distribution of Chang 8₁ tight oil is controlled by sand thickness, mudstone sand content, reservoir lithology and physical properties. Medium and fine sandstones with large thickness, low shale content and good physical properties are conducive to the enrichment and high yield of tight oil.

Conflicts of Interest

The authors declare no conflicts of interest.

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