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Distribution and Geochemical Characteristics of Source Rocks in Chang 7 Member of Qilicun Oilfield in Ordos Basin

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Abstract

In the past, the research on tight oil accumulation in the eastern part of Shanbei slope of Ordos basin is relatively weak, mainly because the effective source rock is not developed in this area, and the crude oil is migrated from Chang 7 source rock in the center of the lake basin. Taking Qilicun Oilfield in Yan'an area as an example, this paper studies the reservoir-forming conditions of Chang 7 tight oil according to the methods and means of well logging, thin section identification, reservoir physical properties and core description, source rock geochemistry and so on. the results show that the hydrocarbon source rocks of Chang 7 member in the study area can be divided into black shale and dark mudstone with a wide distribution range, and the thickness of hydrocarbon source rocks is thinned from southwest to northeast as a whole. Organic geochemical indexes of source rocks reveal that Chang 7 black shale is a high quality source rock. The sand bodies of each subformation of Chang 7 are distributed, but the thickness of the single layer is thin and the physical property of the reservoir is poor, so it is a typical tight reservoir. The comprehensive analysis of the reservoir forming conditions of Chang 7 shows that the study area has a good source rock foundation, poor reservoir conditions and superior reservoir assemblage, but due to the development of vertical macroscopic microfractures, the oil generated by vertical Chang 7 source rocks is mainly overpass Chang 7 reservoir, and the probability of accumulation is small, which indicates that the exploration potential of Chang 7 reservoir in this area is poor as a whole.

Subject Areas

Petroleum Geology

Keywords

Qilicun Oilfield, Hydrocarbon Source Rock, Evaluation of Tight Oil Reservoir Forming Conditions, Chang 7

1. Introduction

Ordos basin is a relatively stable multicycle craton basin [1] [2]; it is the second largest sedimentary basin in China and the main exploration target of tight oil in Ordos Basin. During the sedimentary history of the basin, it has experienced many environments such as rivers and lakes. At present, there are mainly several sedimentary facies in the basin, namely deltas, lakes and rivers. It was formed after the disintegration of the North China Platform at that time, and gradually developed and evolved independently. The whole evolution process was basically in a stable sinking state, and some of them experienced obvious depression migration, thus forming a large sedimentary basin rich in oil, gas, minerals and other resources [3].

From the perspective of structural evolution, the internal structure of Ordos basin is relatively simple and the strata are flat, which is conducive to the preservation of oil and gas. Chang 7 black oil shale and dark mudstone are the main high-quality source rocks in this study area, and Chang 4+5, Chang 6 and Chang 8 reservoirs have poor physical properties, belonging to the main low-permeability and ultra-low-permeability tight reservoirs [4].

2. General Situation of Regional Geology

There are many unconventional resources in China, and there is great room for research and development. Tight oil has also made good achievements in exploration [5]. Because the development history of exploration in tight oil is not far away, there is little knowledge and research on tight oil, especially on the reservoir-forming conditions in tight oil. For the study of tight oil, it is difficult for our existing data and technology to provide enough data and technical experience for the current exploration in tight oil. Because there are essential differences between tight oil reservoir formation and conventional oil reservoir formation, the development experience of conventional reservoirs is also difficult to provide reference experience, which leads to the slow development of theoretical understanding of tight reservoirs, and the exploration cost and production in tight oil are not directly proportional, resulting in great losses. Even though great achievements have been made in the exploration of tight oil in Ordos Basin, the study of tight reservoirs remains to be further studied.

Qilicun Oilfield is located in Yanchang County, Yan'an City, Shaanxi Province, in the east of Yishan Slope in Ordos Basin (**Figure 1**) [6]. The discovery well is Yan 1, and the main oil-bearing horizon is Chang 6 oil layer [6]. The Chang 6 and Chang 7 oil layers in the study area are mainly delta front deposits,

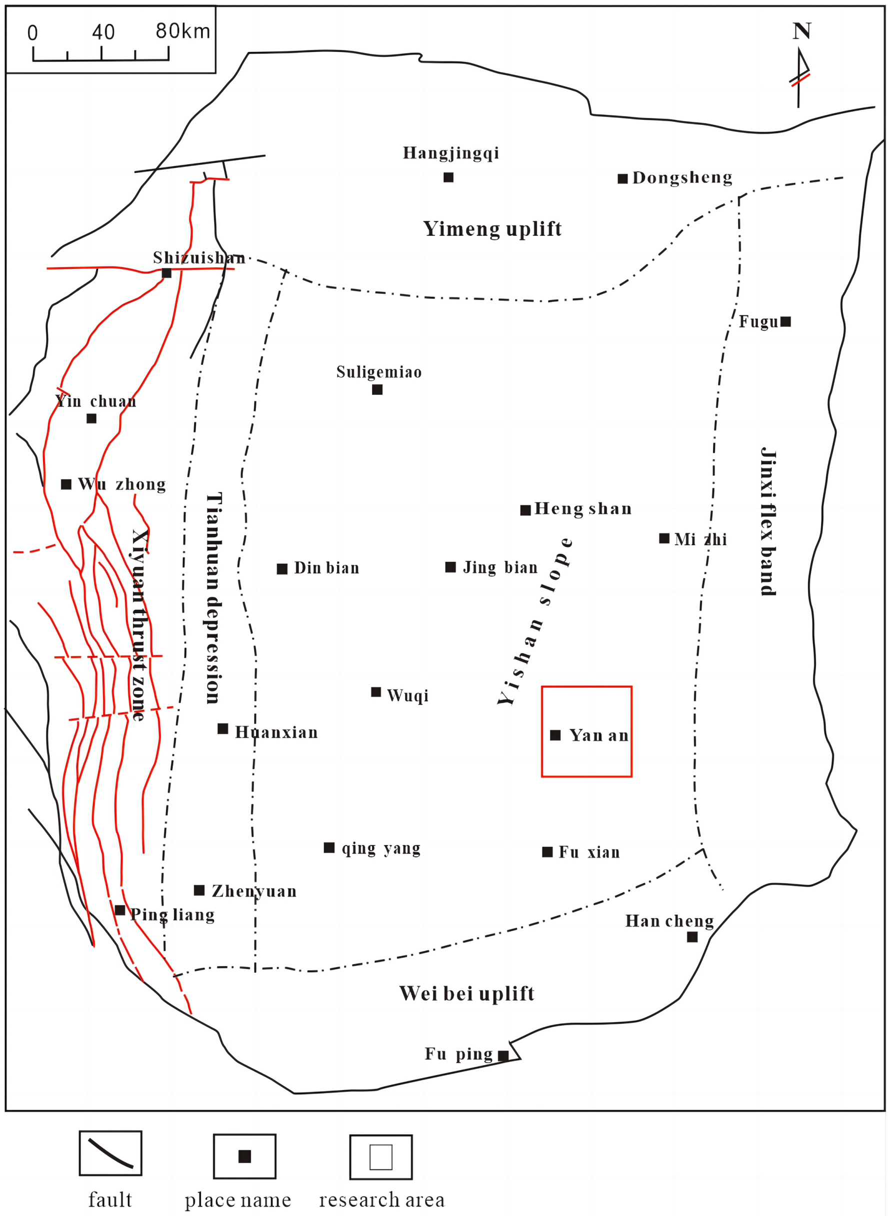

Figure 1. Structural location map of the study area.

and the microfacies of underwater distributary channels, inter-river bays, natural dikes and estuarine sandbars are developed [7]. Chang 6 oil reservoir group is further divided into Chang 6_1-Chang 6_4 oil reservoir subgroups in the study area. Chang 6_1^4 and Chang 6_2^2 are the main pay zones, with good connectivity, and other sublayers are also developed in a small range [6]. Chang 7 reservoir group is divided into Chang 7_1-Chang 7_3 reservoir subgroups. At present, only a few wells have discovered oil reservoirs.

3. Distribution Characteristics of Source Rocks

The source rocks of Chang 7 member in Qilicun Oilfield are divided into two types: black shale and dark mudstone [6]. Most of the fresh faces of black shale cores are dark gray and gray-black. The fresh surface of dark mudstone core is light in color, mostly gray, and most of them are massive structures.

3.1. Vertical Distribution Characteristics of Source Rocks

Because source rocks generally contain more organic matter, the characteristics of logging curves are also obvious. Generally, the logging curves of source rocks have the characteristics of "high natural gamma, high acoustic time difference, high resistivity and low density [8] [9]". According to the high and low logging curves of source rocks, the source rocks of Chang 7 member are divided.

The cores of the two source rocks are obviously different, so it can be seen that their environments are also different. By observing the core, it can be seen that black shale has deeper sedimentary water and stronger reducibility than dark mudstone [6]. It can be seen from the logging curve that the black shale mainly shows high natural gamma curve value, high acoustic time difference curve value, low density curve value and medium-low resistivity value; However, dark mudstone is characterized by high natural gamma curve value, high acoustic time difference curve value, medium-low density and medium-low resistivity, which may mainly reflect that black shale contains more organic matter.

Vertically, according to the well site plan, it will be divided into east-west and north-south directions (**Figure 2**), and the vertical distribution profile of source rocks will be drawn respectively. According to the east-west distribution of source rocks, the thickness of source rocks gradually becomes thinner from west to east, and black shale is basically distributed in Chang 7_3, with a small amount distributed at the bottom of 7_2; from the south-north distribution of source rocks, there is basically no obvious change, and the thickness of source rocks is basically the same.

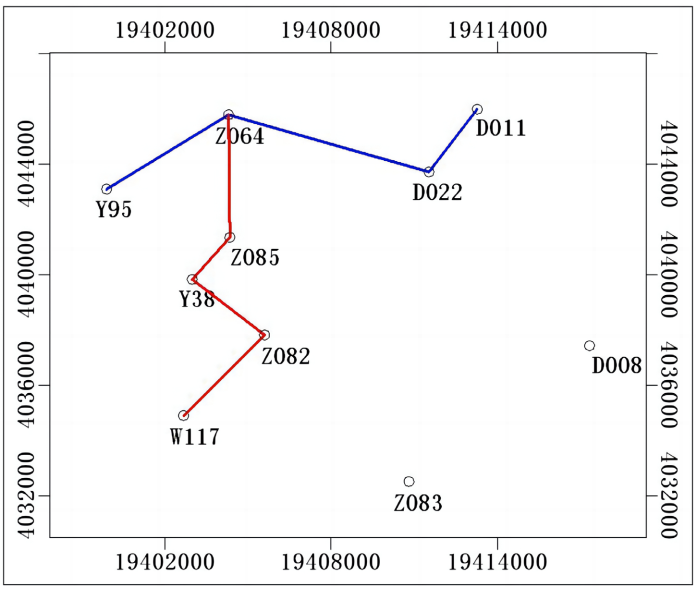

Figure 2. East-West-North-South distribution plan of well Chang 7 in Qilicun oilfield.

3.2. Plane Distribution Characteristics of Source Rocks

It can be seen from the plane distribution map of source rocks (**Figure 3**) that the long source rocks in Qilicun Oilfield are widely distributed, covering the whole study area. On the whole, the thickness of source rocks decreases from southwest to northeast, and the change trend is obvious. The total thickness of Chang 7 source rock is 89.35 m, basically in the range of 11.44 - 1.13 m, with an average of 8.9345 m.

4. Geochemical Characteristics of Source Rocks

4.1. Organic Matter Abundance

Geochemical test and analysis of Chang 7 source rocks in Qilicun Oilfield show that the total organic carbon content is basically in the range of 0.15% - 6.59%, with an average of 2.32%, of which black shale is 1.05% - 4.1%, with an average of 2.69%. Dark mudstone ranges from 0.15% to 6.59%, with an average of 1. 8%. Hydrocarbon generation potential ($S_1 + S_2$) content is in the range of 0.18 - 22.39 mg/g, with an average of 7.66 mg/g, in which black shale is in the range of 0.18 - 17.11 mg/g, with an average of 9.45 mg/g; dark mudstone ranges from 0.18 to 22.3 mg/g, with an average of 5.75 mg/g; the content of chloroform asphalt "A"

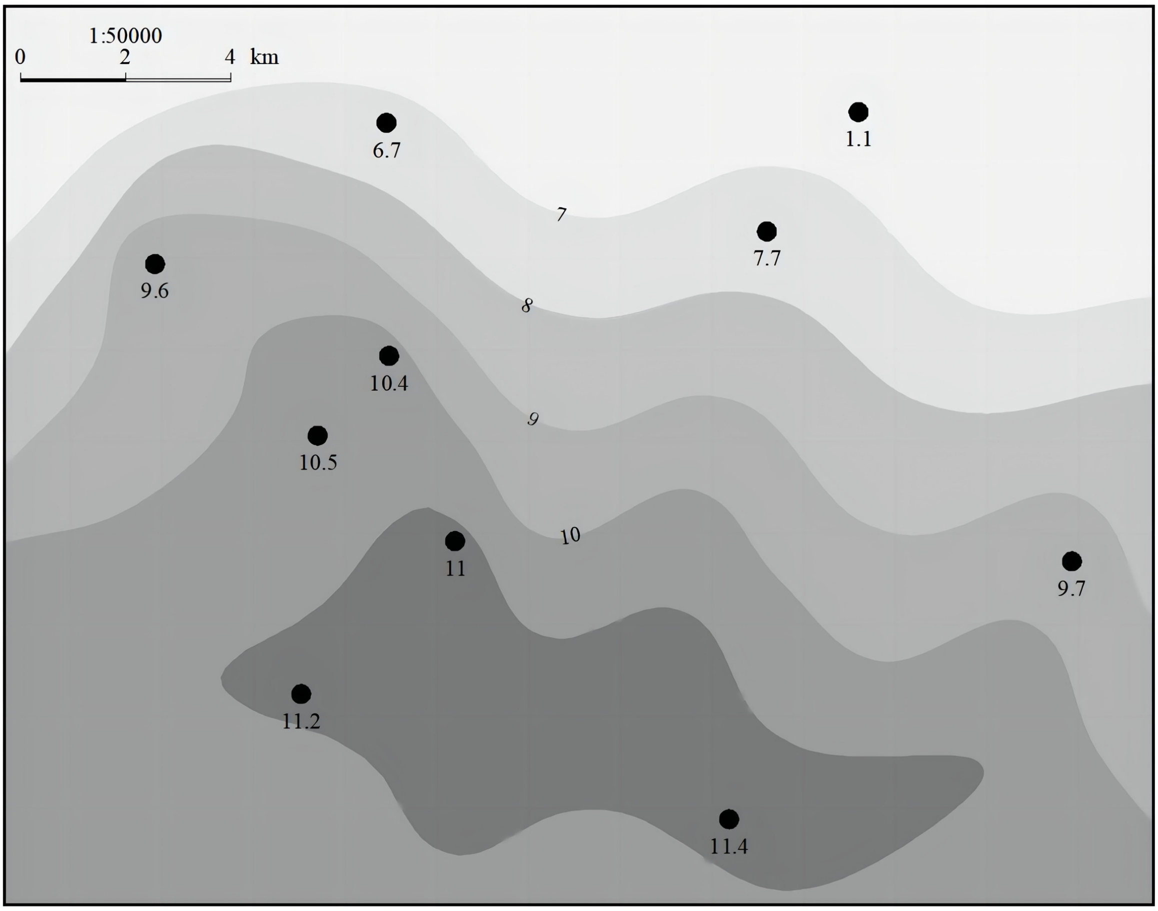

Figure 3. Isogram of Chang 7 source rock thickness in Qilicun Oilfield.

is between 0.13% and 0.72%, with an average of 0.37%.

The distribution of black shale is 0.33% - 0.72%, with an average of 0.46%. Dark mudstone is between 0.13% and 0.41%, with an average of 0.14%。

According to the industry standard SY/T 5735-1995 [10], the source rock of Chang 7 in Qilicun Oilfield is evaluated, and the organic carbon type is the "best" source rock type. The hydrocarbon generation potential type is "good" source rock type; Chloroform asphalt "A" is the "best" source rock type, so it is concluded that Chang 7 source rocks basically belong to "best" and "good" source rocks.

4.2. Type of Organic Matter

The hydrocarbon generation ability of organic matter depends on its source and composition, and the type of organic matter is one of the indexes to evaluate source rocks. In this paper, based on the comprehensive analysis of the pyrolysis of source rocks, organic carbon analysis results, kerogen microstructure and stable carbon isotopes in kerogen microscopic examination results, it is considered that the organic matter types of Chang 7 source rocks in Qilicun Oilfield are good, mainly I and II_1 types.

4.2.1. Pyrolysis Parameters of Source Rocks

The organic matter types of source rocks are obtained by throwing points on the chart of organic matter type division. The results show that the organic matter of Chang 7 source rocks in Qilicun Oilfield is mainly I-II_1 type, and the organic matter type is generally good, mainly oil generation.

4.2.2. Microstructure of Kerogen

According to the microscopic composition of kerogen (**Table 1**), it can be concluded that the content of sapropelic group in kerogen of Chang 7 source rock is the highest; followed by vitrinite, basically containing no crustaceous group and a small amount of inertinite group, indicating that the parent material of source rocks is lower aquatic organisms and higher plants. The formula is used to calculate the organic matter type index (TI) [11]. When TI ≥ 80, the kerogen type of T source rock is Type I, when 40 ≤ Ti < 80, it is Type II_1, and when 0 ≤ Ti < 40, it is Type II_2. When Ti < 0, kerogen type of source rock is type III. Finally, it is concluded that the kerogen types of Chang 7 source rocks are mainly II_1-II_2.

4.2.3. Stable Carbon Isotope

The characteristics of stable carbon isotope $\delta^{13}C$ of kerogen mainly depend on the type and evolution degree of organic matter [12] [13], and the carbon isotope is relatively stable, so it can be used to judge the type of organic matter. According to the carbon isotope data of 10 samples of source rocks in the study area, it can be concluded that the $\delta^{13}C$ content of source rocks is in the range of −31.86‰ - −28.3‰, which corresponds to the typical sapropelic type of the three-point method. Standard sapropelic type I_1 in Huang Difan classification; the humic and sapropelic II_2 in SY/T5735-1995 classification standard.

Table 1. Calculation table of organic maceral and type index of kerogen in Chang 7 source rock of Qilicun Oilfield.

Depth (m)	Layer	Sapropelic formation (%)	Crustal formation (%)	Vitreous group (%)	Inert group (%)	Type index	Type
522.8	Chang 7_2	62.3	0	37.3	0	34	II_2
524.7	Chang 7_2	58	0	42	0	26.5	II_2
526.4	Chang 7_2	56.3	0	43.7	0	23.5	II_2
527.6	Chang 7_2	43.7	0	56.3	0	1.5	II_2
530.2	Chang 7_2	58	0	42	0	26.5	II_2
533.9	Chang 7_3	64	0	35.7	0.3	36.9	II_2
535	Chang 7_3	57.3	0	42.3	0.3	25.3	II_2
537.7	Chang 7_3	62	0	37.7	0.3	33.4	II_2
540.9	Chang 7_3	65.7	0	34.3	0	40	II_1
543.2	Chang 7_3	69	0	31	0	45.8	II_1
546.7	Chang 7_3	64.7	0	35.3	0	38.2	II_2
554.8	Chang 7_3	63.7	0	36.3	0	36.5	II_2

5. Comprehensive Evaluation of Source Rocks and Its Exploration Significance

Based on the comprehensive evaluation of the distribution and geochemical characteristics of Chang 7 source rocks in Qilicun Oilfield in the eastern margin of Ordos Basin, it is considered that Chang 7 source rocks are widely distributed in the study area. Although the thickness of black shale is relatively thin, the thickness of dark mudstone is relatively large, which makes up for the shortage of the overall source rocks to some extent. Moreover, the source rocks are rich in organic matter, in which black shale meets the standard of "best" source rocks and most dark mudstone also meets the standard of "medium-good" source rocks. Generally, the types of organic matter are I-II_1, all of which are mainly oil generation. Many maturity parameters show that Chang 7 source rocks have reached maturity and entered the main oil generation stage. It can be seen that Chang 7 black shale and dark mudstone are effective and good quality source rocks in Qilicun Oilfield.

There are many unconventional resources in China, and there is great room for research and development. Tight oil has also made good achievements in exploration [5]. Because the development history of exploration in tight oil is not far away, there is little knowledge and research on tight oil, especially on the reservoir-forming conditions in tight oil. For the study of tight oil, it is difficult for our existing data and technology to provide enough data and technical experience for the current exploration in tight oil. Because there are essential differences between tight oil reservoir formation and conventional oil reservoir formation, the development experience of conventional reservoirs is also difficult to provide reference experience, which leads to the slow development of theoretical understanding of tight reservoirs, and the exploration cost and production in tight oil are not directly proportional, resulting in great losses. The discovery of Chang 7 effective source rocks in Qilicun Oilfield has enhanced the exploration confidence, which indicates that the oilfield and its nearby areas have a good oil-forming foundation.

6. Conclusions

1) The source rocks in Chang 7 member of Qilicun Oilfield in Ordos Basin are widely distributed, and the thickness of source rocks is getting thinner from southwest to northeast; the average content of total organic carbon is 2.32%, the average hydrocarbon generation potential is 7.66 mg/g, and the average content of chloroform asphalt "A" is 0.37%, so the source rock types of Chang 7 in Qilicun Oilfield basically belong to the "best" or "good" categories. The types of organic matter are mainly I and II_1.

2) Although geochemical indicators of source rocks in Chang 7 member of Qilicun Oilfield indicate that Chang 7 source rocks belong to the "best" or "good" source rocks, comprehensive analysis shows that the exploration potential of Chang 7 reservoir in Qilicun Oilfield is small due to the relatively thin thickness of source rocks, with an average of less than 10m, extremely poor reservoir physical properties and developed fractures.

Conflicts of Interest

The authors declare no conflicts of interest.

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