Analysis of physical properties of middle-deep reservoirs in the east of Jizhong Depression

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Abstract. The Jizhong Depression is one of the hot spots for oil and gas exploration in North China. As the Jizhong Depression has the largest area and richest oil and gas resources, the Raoyang Depression has good prospects for exploration. This paper takes the middle-deep reservoirs of the Shahejie Formation in the Raoyang Depression as the research object. Aiming at the problem of the unclear characteristics of the middle-deep reservoirs in the Raoyang Depression, using core description, thin section identification, and cathodoluminescence technology, the physical properties of the middle-deep reservoirs in Shahejie are clarified. The following points of understanding have been obtained: The rock types of Shahejie Formation in Raoyang area are mainly feldspar sandstone and detrital feldspar, followed by feldspar detrital sandstone and feldspar quartz sandstone. The main mineral content of different structural belts is different. The quartz content in Suning and Maxi areas is higher than that in Liuchu and Dawangzhuang areas. The feldspar content in Liuchu and Dawangzhuang areas is higher than that in Suning, Maxi and Liuxi areas. The Maxi area has the highest lithic content. There are 7 types of pores, including intergranular pores, intragranular pores, granular dissolved pores, mold pores, intergranular dissolved pores, intragranular dissolved pores, and intergranular pores. The porosity in Raoyang area is between 0.85% and 35.26 % with the average value of 12.05%. The permeability is 0.01mD-1312mD, and the average value is 12.75mD. It belongs to low porosity-low permeability reservoirs. Finally, combined with sedimentary facies characteristics and actual drilling and logging data, the reservoir division of the study area is completed, and 10 favorable areas are proposed. The research results provide a reference for the next step in the study of the physical characteristics of the middle and deep reservoirs in the eastern part of the Jizhong Depression.

1. Introduction

With the continuous deepening of oil and gas exploration, mid-deep oil and gas has become a key exploration direction. The unclear reservoir properties are one of the factors restricting mid-deep exploration. Predecessors have done a lot of discussions on the genetic mechanism of mid-deep reservoirs. For example, Cao Yingchang (2014) pointed out that early abnormal high pressure was the main controlling factor for the formation of mid-deep high-quality reservoirs in Baxian Sag [1]. Wang Yuanjun et al. (2012) pointed out that the diagenesis is the main controlling factor for the mid-deep reservoirs in the Shinan slope belt of the Bozhong Depression [2]. Guan Ping (2011) pointed out that sedimentation is the main controlling factor for the mid-deep high-quality reservoirs in the alkali
mountain structure of the Qaidam Basin [3]. It can be seen that the main controlling factors of different blocks are different, and the physical characteristics of the main controlling factors of the reservoir should be studied in combination with the geological background [4-5].

The eastern part of the Jizhong Depression refers to the east of Daxing Uplift-Rongcheng Uplift-Gaoyang Low Uplift, including 5 depressions in Dachang, Langgu, Baxian and Raoyang Depressions. Among them, the Raoyang sag is the most oil-rich sag in the eastern part of the Jizhong Depression. Due to the lack of core data from mid-deep wells, there is a lack of understanding of the physical properties of mid-deep reservoirs. With the continuous deepening of oil and gas exploration, there is an urgent need to recognize the physical characteristics of the mid-deep reservoirs [6]. The Raoyang sag is structurally located in the southeast of the Jizhong Depression. The sag is interspersed with uplift and sags. It can be subdivided into five structural belts, namely, the Maxi area, the Liuxi area, the Liuchu area, the Suning area, and the Dawangzhuang area. Alluvial fans, fluvial facies, fan deltas, and discerning river delta sedimentary systems are developed in the study area. The target horizon of this study is the Shahejie Formation.

2. Methods and materials

Experimental materials: SYJ-200 automatic precision cutting machine (Shenyang Kejing Automation Equipment Co., Ltd.), GPC-80A precision grinding and polishing controller (Shenyang Kejing Automation Equipment Co., Ltd.), FZ-20 vacuum drying oven (Nanjing Runen Equipment Co., Ltd.) Company), Olympus microscope (Nikon Co., Ltd. in Japan), emery, epoxy resin, curing agent, dyeing agent, fir glue, etc.

Experimental method: The samples in the test and analysis are all from the core section of the study area (Table 1). Thin section production: We select representative rock samples, wash the samples, and maintain a vacuum state during the production process. After rough grinding, fine grinding, and fine grinding, the thickness of the rock product is 0.03mm, which is labeled for identification and use.

| Sample number | Well name | Sample number | Well name | Sample number | Well name |
|---------------|-----------|---------------|-----------|---------------|-----------|
| JD-1          | L101      | 3678-3700     | JD-11     | CS2           | 4285.65-4288.69 |
| JD-2          | CS1       | 4293.25-4298.69 | JD-12     | N202         | 4123.12-4125.19 |
| JD-3          | N201      | 4122-4123.89  | JD-13     | N204         | 4120.63-4122.05 |
| JD-4          | C22       | 4121.23-4123.65 | JD-14     | C20          | 3678.49-3700.72 |
| JD-5          | LG2       | 3678-3700     | JD-15     | C21          | 4294.15-4297.29 |
| JD-6          | CS1       | 4293.25-4298.69 | JD-16     | L103         | 4121.30-4123.29 |
| JD-7          | N201      | 4122-4123.89  | JD-17     | L109         | 4121.03-4123.55 |
| JD-8          | C22       | 4121.23-4123.65 | JD-18     | L104        | 3678.29-3700.28 |
| JD-9          | LG2       | 3678-3700     | JD-19     | LG1          | 4193.25-4198.39 |
| JD-10         | CS1       | 4293.25-4298.69 | JD-20     | LG4          | 4291.45-4296.59 |

3. Results and analysis

3.1. Petrological characteristics

The rock types of Shahejie Formation in Raoyang area are dominated by feldspar sandstone and detrital feldspar, followed by feldspar detrital sandstone and feldspar quartz sandstone. The content of main minerals in different tectonic belts is different. For example, the average content of quartz in Suning area is 54% ~ 59%, the average content of quartz in Masi area is 50% ~ 55%, the average content of quartz in Liuchu area and Dawangzhuang area is 38% ~ 49%, the average content of feldspar in Suning area is 28.5% ~ 35.0%, and the average content of feldspar in Maxi area is 20.0% ~ 38.0%. The average content of feldspar in Liuchu area is 40.7%, the average content of feldspar in Liuxi area is 35.3% ~ 36.0%, the average content of feldspar in Dawangzhuang area is 55.0%, the average content of cuttings
in Suning area is 6.2% ~ 16.2%, the average content of cuttings in Masi area is 11.0% ~ 24.0, the average content of cuttings in Dawangzhuang area is 7.0%, and the average content of cuttings in Liuxi area is 11.0% ~ 14.0%. The content of Swallow’s volume in Liuchu is 10.7% out of thin air in the area, and the main mineral content of different structural belts is different. The content of quartz in Suning and Masi area is higher than that in Liuchu and Dawangzhuang areas, and the content of feldspar in Liuchu and Dawangzhuang areas is higher than that of Suning. The highest lithic content is found in Masi area, Liuxi area, and Maxi area. The overall sortability of Raoyang area is medium, among which Dawangzhuang area is the best, followed by Liuchu and Suning areas, and Maxi area is the worst. The roundness is mainly sub-circular-sub-angular.

3.2. Reservoir pore types
There are 7 pore types developed in Raoyang area: intergranular pores, intragranular pores, micropores, intergranular pores, intragranular pores, granular pores, and mold pores, including intergranular pores, intragranular pores, and intergranular pores. Mainly. Intergranular pores, intragranular pores, and micropores are primary pores, which are still retained in the middle and deep layers, but they do not account for much. Secondary quartz crystals, flake chlorite, and hairy illite are common to fill the intergranular pores. Secondary pores are developed, especially feldspar dissolution is developed, and potassium feldspar dissolution is mostly developed. The residual particles can be seen in blue light and green-gray light under the cathodoluminescence (Figure 1).

Figure 1. Microscopic photos of researched pore types (a: intergranular pores, 3699.24m, L101; b: micropores, 3703.64m, L101; c: intergranular pores, 3546.23m, N201; d: intergranular pores, intragranular pores, 4122.35m, C22; e: Cast film hole, 3547.36m, N201; f: intragranular dissolved pore, 4010.32m, LG2; g: cast film hole, 3811.35m, L101; h: crack, 3811.25m, L101; i: microcrack).

3.3. Reservoir physical characteristics
The porosity of the study area is 0.90% ~ 32.26%, with an average value of 10.05%, of which the porosity in the Maxi area is 2.70% ~ 25.50%, and the average value is 11.37%. The porosity in the Suning area is 1.36% ~ 16.63%, and the average value is 8.53%. The porosity of Zhuang area is 0.90% ~ 32.26%, and the average is 11.20%. The porosity of Liuxi area is 3.60% ~ 20.40%, and the average is 10.19%. The porosity of Liuchu area is 2.80% ~ 15.20%, and the average is 8.98%, which shows that the Raoyang area is a low-porosity reservoir, the average porosity of each area is not much different, and high-porosity and ultra-high pores are locally developed (Figure 2a). The permeability of Raoyang
The permeability of Maxi area is 0.01mD~1292mD, the average is 12.57mD. The permeability of Masi area is 0.04mD-7.41mD, the average is 1.71mD. The permeability of Suning area is 0.02mD-379.00mD, and the average is 6.05mD. The regional permeability of Dawangzhuang is 0.01mD~14.55mD, and the average is 14.55mD. The permeability of Liuxi area is 0.05mD-188.00mD, and the average is 39.76mD. The permeability of Liuchu area is 0.01mD-17.30mD, and the average is 0.76mD. The Raoyang area is a low-permeability reservoir, and the Liuchu area is an ultra-low-permeability reservoir (Figure 2b).

Figure 2. Porosity and permeability histograms of different blocks in the study area (a, porosity; b, permeability).
3.4. Reservoir evaluation

Based on porosity and permeability, combined with mercury intrusion data, the reservoirs in the Raoyang area are divided into four types: Type I reservoirs with porosity > 25%, permeability > 50 mD, drainage pressure < 0.4 MPa, median pressure < 0.3 MPa, maximum contribution saturation > 85%, and irreducible water saturation < 15%; Type II reservoir with porosity between 15% - 25%, permeability between 10 mD - 50 mD, drainage pressure between 0.4 MPa - 1.63 MPa, median pressure between 0.3 MPa - 2.43 MPa, maximum contribution saturation between 75% - 85%, and the irreducible water saturation 15% - 25%; The porosity of type III reservoir is 10% - 15%, the permeability is 1 mD - 10 mD, drainage pressure is 1.63 MPa - 2.21 MPa, median pressure is 1.56 MPa - 2.43 MPa, maximum contribution saturation is 75% - 80%, and irreducible water saturation is 20% - 25%. Type IV reservoir has the porosity of 5% - 10%, permeability < 1 mD, drainage pressure < 3.42 MPa, median pressure > 2.43 MPa, maximum tribute saturation 50% - 75%, and bound water saturation 25% - 50%.

The types of reservoirs in different structural belts are different. For example, R95 in the northern Renqiu area is dominated by type II reservoirs, accounting for 80%. Fan delta facies deposits are developed in the Maxi area, dominated by type II + type III reservoirs. For example, in M69, type II reservoirs account for 25%, type III reservoirs account for 65%, and type I+IV reservoirs account for 10%. The Suning area develops braided river delta plain subfacies deposits, the plain area mainly develops type IV reservoirs, and the front area mainly develops type III reservoirs. The proportion of type IV reservoirs in the plain sedimentary environment R22 accounts for 95%. The front deposits Type III reservoirs in environmental N201 account for 80%. The Dawangzhuang area develops semi-deep lake-deep lake subfacies deposits, and mainly develops Type II and Type III reservoirs. For example, type II reservoirs in Well L31 account for 38%, and type III reservoirs account for 31%. In Liuxi area, there are mainly fan delta front subfacies deposits, mainly type III reservoirs, for example, type III reservoirs in L54 account for 70%. The Liuchu area develops sedimentary braided river delta plain subfacies and frontal subfacies deposits, mainly developing type III reservoirs. For example, the proportion of type III reservoirs in CG11 is 90%, and the proportion of type III reservoirs in C202 is 59%. The Wuqiang area has the best physical properties, mainly type I and type II reservoirs. For example, the percentage of type I reservoirs in Q1 is 98%, and the percentage of type II reservoirs in Q7 is 90%.

Zhang Ping (2016) pointed out that the development of high-quality reservoirs in the sag area of the Raoyang Sag is affected by both tectonic and sedimentary processes. Reservoirs that are well sorted, have high feldspar content, develop abnormally high pressure, and have little late carbonate cement. Finally, combining sedimentary facies belts, actual drilling logging data, and reservoir conditions, a total of 10 favorable areas are predicted: N35-N33, N5-N2-N301-N302, NG3, L104-L425-L434, L483-L73, L58, CS1-C22-C29, C21, L43-L83-L4405, L408 well area. In these favorable areas, there are mostly coastal shallow lake beach bars and frontal subfacies of discerning river deltas, with type II reservoirs being the main ones.

4. Conclusion

(1) The rock types of the Shahejie Formation in the Raoyang area of the Raoyang Depression are dominated by feldspar sandstone and detrital feldspar, followed by feldspar detrital sandstone and feldspar quartz sandstone. The main mineral content of different structural belts is different. There are 7 types of pores: intergranular pores, intragranular pores, micropores, intergranular pores, intragranular pores, granular pores, and mold pores. The porosity is between 0.90% - 32.26%, and the average value is 10.05%. The permeability is 0.01 mD - 1292 mD, and the average value is 12.57 mD. The reservoir belongs to low porosity-low permeability reservoirs.

(2) Based on reservoir evaluation, the reservoirs are mainly type II and III reservoirs. Type IV is mostly developed in the southern part of the study area, and type I reservoirs are only developed in Wuqiang area. High-quality reservoirs are mainly developed in the front water of braided river delta, lower distributary channel sand, coastal shallow lake beach bar sand body, and fan delta front sand body.
10 favorable areas in the study area are predicted: N35-N33, N5-N2-N301-N302, NG3, L104-L425-L434, L483-L73, L58, CS1-C22-C29, C21, L43-L83-L4405, L408.

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