Scientific Research Publishing

Journal of Geoscience and Environment Protection, 2024, 12, 1-11
https://www.scirp.org/journal/gep
ISSN Online: 2327-4344
ISSN Print: 2327-4336

Evaluation of Chang 2 Reservoir in Zichang Area, Ordos Basin

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How to cite this paper: Du, Z. W., Ping, Z. Y., & Chen, F. (2024). Evaluation of Chang 2 Reservoir in Zichang Area, Ordos Basin. *Journal of Geoscience and Environment Protection, 12,* 1-11.
https://doi.org/10.4236/gep.2024.124001

Received: March 11, 2024
Accepted: April 9, 2024
Published: April 12, 2024

Abstract

In this paper, the Chang 2 reservoir in Zichang Area of Ordos Basin, the second largest sedimentary basin in China, is classified and evaluated by using logging and core data, thin section identification and electron microscopy. The main sedimentary microfacies of Chang 2_1^3 is braided river delta sedimentary system in geological history, and there are three main sedimentary microfacies types: swamp microfacies, distributary channel microfacies and natural embankment microfacies on land. The heterogeneity in the study area is as follows: Chang 2_1^2 formation has the strongest heterogeneity, followed by Chang 2_1^1 formation with strong heterogeneity, and finally Chang 2_1^3 formation with medium heterogeneity. The reservoirs of Chang 2 member in the study area are dominated by III_a, II_b and III_b, and the reservoirs are mainly composed of ultra-low porosity and low permeability reservoirs and low porosity and low permeability reservoirs.

Keywords

Zichang Area, Sedimentary Microfacies, Reservoir Assessment, Ordos Basin

1. Introduction

In recent years, the field of petroleum geology in China has been greatly developed, and the way of "throwing straw hat and selecting well location" has gradually changed into the way of supporting theory and practice (Wang & Shi, 1999; Nie et al., 2000; Housekneeht, 1987), and the geological model of oil-gas reservoir and computer three-dimensional model have been established (Best et al., 2009; Amaefule et al., 1993; Cross, 1993). There are these changes in reservoir classification evaluation: 1) from macro to micro; 2) from qualitative to quantitative; 3) from single to comprehensive; 4) from the emergence of new technology to application (Weimer, 1994; Qiu et al., 1997; Wang, 1985; Mu, 1999).

Since the 21st century, Yanchang Oilfield has gradually begun small-scale development in some areas. After five or six years of production and development, it has emerged in scale and reached the capacity of mass production. After more than ten years of large-scale exploitation, its original formation energy has gradually declined, requiring water injection development and the deployment of water injection Wells. In the development process of Zichang area, it can be divided into three stages according to its development mode and scale: initial oil test and production stage, natural energy development stage and water flooding development stage (Deng, 2011).

It has been many years since the injection Wells in Zichang area were put into use and converted into water injection. With the passage of time and continuous exploitation, the remaining recoverable oil and gas resources in this area are decreasing year by year. However, the demand of oilfield enterprises is to pursue long-term stable development, and to gradually increase production to cope with the domestic oil and gas market. Therefore, we need to study and evaluate the corresponding development layer (Chang 2 reservoir) in the study area.

2. Geological Setting

Ordos Basin is one of the large sedimentary basins in China. Located on land, it not only has rich oil and gas resources, but also rich mineral resources. Compared with offshore oil and gas resources, the onshore basin has considerable advantages. Coal, uranium and salt mines, covering an area of 3.7×10^5 km^2, span the five provinces of Shanxi, Gansu, Ningxia, Shaanxi and Inner Mongolia (Liu et al., 2006; Wu et al., 2004).

Zichang area is located in the eastern part of Shanbei Slope of Ordos Basin (**Figure 1**). The oil-bearing strata in this area are Chang Yanchang 2, Chang 3, Chang 4 + 5, Chang 6 and Chang 8 of the Upper Triassic Series. The reservoir depth is 0.3 - 1.3 km, and the production strata are mainly Chang Yanchang 2 and Chang 6 of the Upper Triassic Series, which are typical "three low" reservoirs. The target layer of this study is Chang 2 reservoir, which has the characteristics of large oil thickness, shallow burial depth, rich oil, high initial production and rapid decline (Tu, 2019), and the general burial depth is 0.34 - 0.56 km.

According to previous studies, the Chang 2 reservoir in this area is further divided into three sand groups: Chang 2_1, Chang 2_2 and Chang 2_3; According to the sedimentary cycle, Chang 2_1 is further divided into three sub-layers, namely, Chang 2_1^1, Chang 2_1^2 and Chang 2_1^3. According to the sedimentary characteristics, Chang 2_2 is further divided into two small layers: Chang 2_2^1 and Chang 2_2^2; Long 2_3 is not further divided.

3. Sedimentary Facies Division

Sedimentary facies refers to the sum of the environment, conditions and characteristics of sediments. The characteristics of its division are: the same phase is

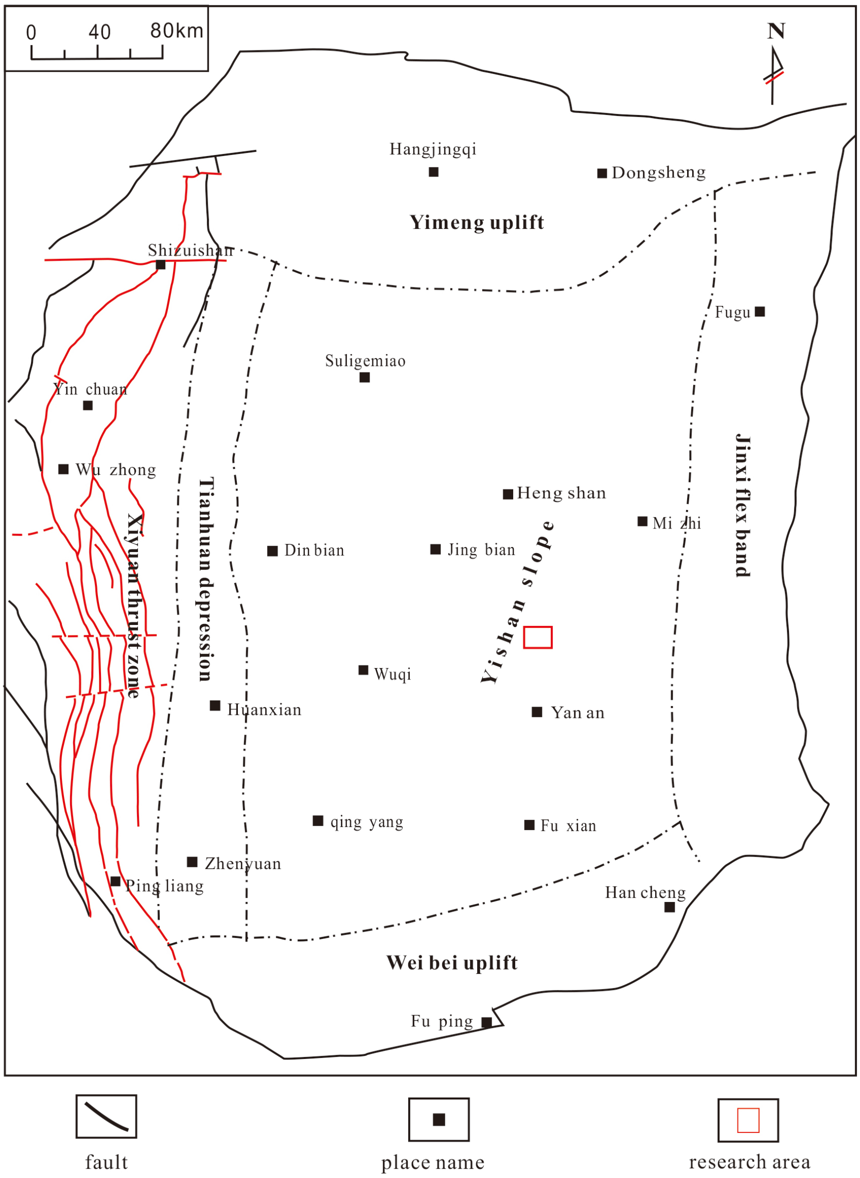

Figure 1. Study area location map.

composed of rocks with the same composition, and the same group is composed in the same geographical area. The sedimentary facies can be divided into continental facies, transitional facies and Marine facies. Continental facies generally include: desert phase, glacier phase, river phase, lake phase, swamp phase, cave equal; The sea-land transition generally includes: delta phase and estuary are equal; Marine facies generally include: coastal facies, shallow Marine basin facies, abyssal facies and abyssal facies; The division of these zones mainly depends on the generation environment of the sedimentary rocks inside them. The identification of these rocks depends not only on the ancient generation environment and the composition structure of the rocks, but also on the biological fossils and microbial fossils contained therein (Li, 2012). Sedimentary facies is the spatial distribution characteristics of the actual physical state of the sedimentary environment, and its formation conditions are controlled by two major factors, namely, time and space, which are also important indicators to control the formation and development of sand bodies.

Sedimentary facies can be further divided into different subfacies, namely sedimentary microfacies, which also play a very important role in the development of oil and gas fields. Sedimentary microfacies refers to the smallest unit in the subfacies zone with unique rock structure, structure, thickness, rhythm and other sedimentary characteristics on the profile as well as certain plane configuration rules (Fang, 2012).

3.1. Sedimentary Facies Symbol

It is necessary to refer to sedimentary facies markers to reasonably delineate the distribution of sand bodies. The two main aspects of sedimentary facies research are facies markers and profile sedimentary sequence.

The rock type of Chang 2 formation is mainly feldspar sandstone, and the composition of sandstone is mainly feldspar, quartz and a small amount of dark minerals. According to the sediment characteristics of the study area, the sediment of Chang 2 sand layer has a binary structure characteristic of fluvial sediments with coarse bottom and fine top. However, unlike the rhythmic cycle in coastal shallow sea sediments, its sedimentary cycle is incomplete and there are many missing phenomena, which is a significant feature of braided channel sediments (Yang & Wang, 2021). In the cap section, there are frequently superimposed massive massive sand bodies, the lithology is mainly medium-fine grained arkose, the content of mud is low, and the ratio of sand to mud is large. In geological history, water flow increased and decreased at times due to the influence of water flow flooding. As a result, water flow often washed out the original river channel horizontally, resulting in a new historical subversion of the river channel. With the advancement of sedimentary evolution, the sedimentary sand bodies were irregularly superimposed vertically, resulting in the formation of a thick massive sand body with a high ratio of sand to mud. These are the notable sedimentary features of braided rivers.

3.2. Sedimentary Microfacies Division

The whole Chang 2 stage lake basin of Ordos Basin gradually shrank, due to the strong late uplift and denudation, only in the inner part of the lake basin and some parts of the southern part, and the southwestern part of the lake basin was completely denudated. Due to the continuous contraction of the lake basin, the unified lake basin situation was close to collapse, further plains and swamps, and the development of river subfacies or plain distributary channels was an important feature of this period. At this time, braided river sediments were very developed, and due to the uplifting of the provenance area, the grain size of the sediments was relatively coarser, which became an important oil and gas accumulation area.

The Chang 2 strata in the study area belong to the delta plain facies sedimentary system in the geological history period, mainly channel sand bodies, frequent migration in the plane direction, and large distribution. According to the data in the study area, it can be judged that there are mainly three microfacies types in the study area: swamps, water distributary channels and natural levees on land (**Figure 2**).

4. Reservoir Characteristics

4.1. Petrological Characteristics of Reservoir

According to the observation of core data collected in the study area, as well as the identification results of thin sections of cast bodies and thin sections of rocks from multiple Wells, the lithology of Chang 2 reservoir in the study area is: gray fine-grained lithic feldspar sandstone, gray white feldspar sandstone, and the rocks contained in the second are: Gray-gray silt-grained feldspar sandstone, gray-black medium-fine grained feldspar sandstone, grayish-white medium-grained feldspar sandstone; The average content of feldspar is 27.97%, the average content of quartz is 52.48% and the average content of rock debris is 2.59% (**Figure 3**).

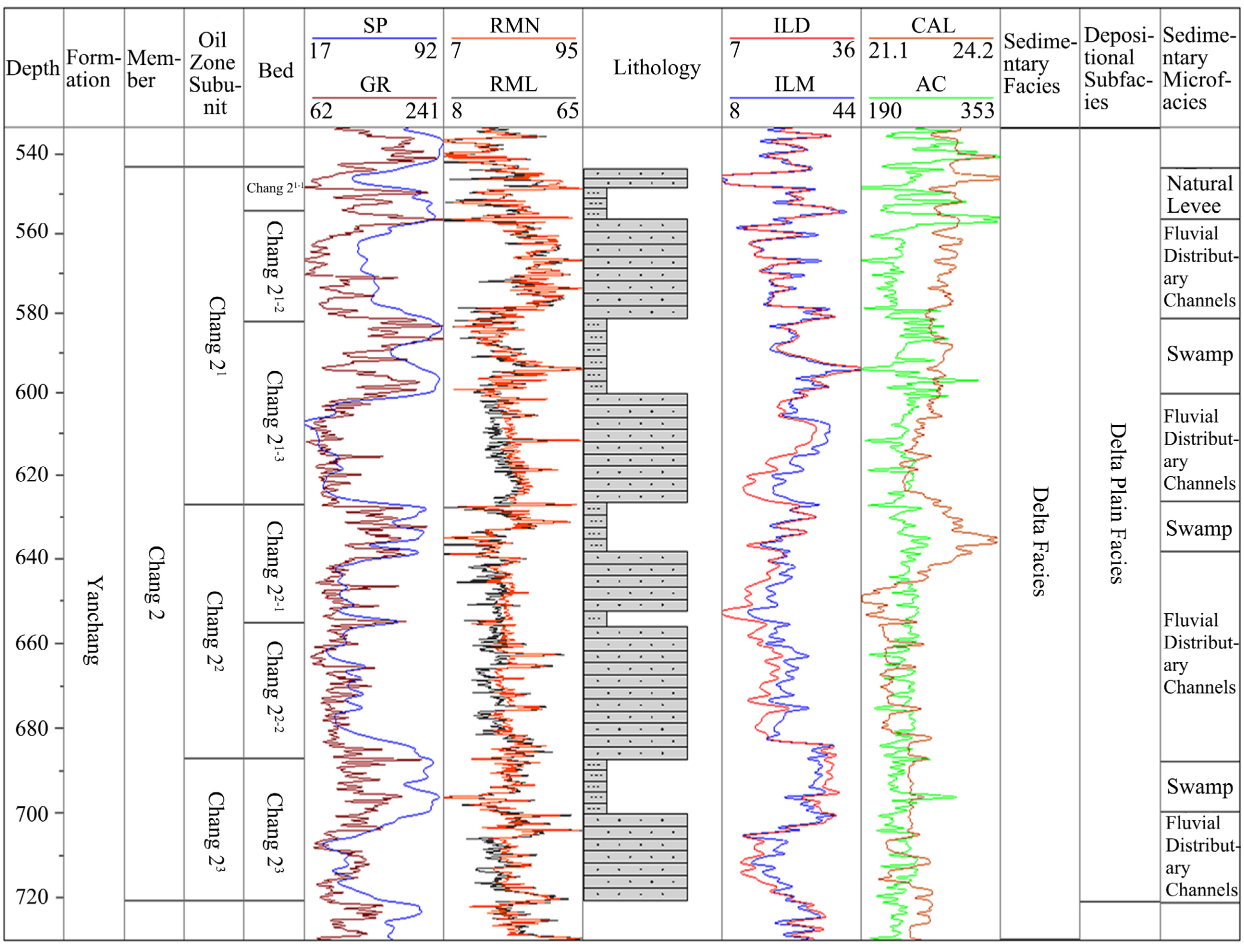

Figure 2. Classification of sedimentary microfacies in Chang 2 reservoir.

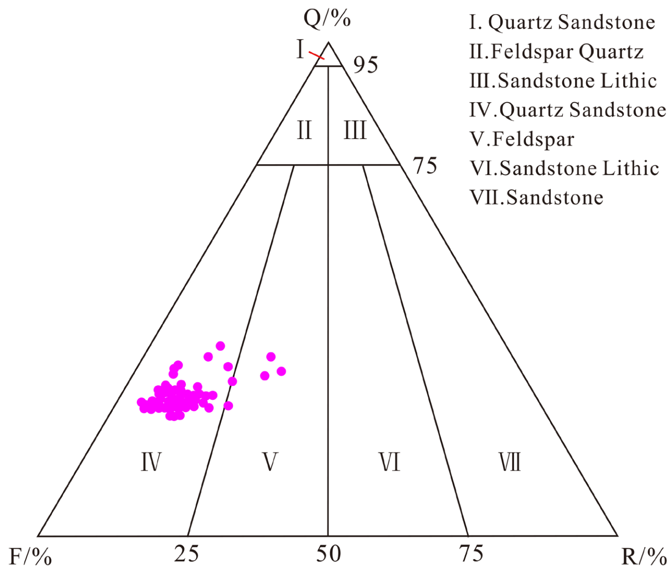

Figure 3. Triangle diagram of percentage of rock composition of Chang 2 oil formation.

4.2. Physical Characteristics

In terms of the porosity difference of Chang 21 reservoir in this area, its maximum and minimum differences are also large, up to 13.1%, in which the minimum porosity is 5.2%, the maximum porosity is 18.3%, and the average porosity is 11.9%. The main distribution range of porosity is from 5% to 16%, and the number of samples in this range accounts for 91.6% of the total number of samples, and its peak range is from 12% to 16% (**Figure 4(a)**). In terms of the permeability of Chang 21 reservoir in the study area, the difference is quite different. The maximum permeability is 28.04×10^{-3} μm^2, the minimum permeability is 0.01×10^{-3} μm^2, and the total permeability is 8.5×10^{-3} μm^2, which is the average value. It can be seen from the permeability frequency distribution diagram that the frequency distribution range is wide, the main frequency concentration is poor and the main frequency concentration of the permeability is poor. The permeability is mainly distributed in the interval of $(2 - 14) \times 10^{-3}$ μm^2, in which the number of samples distributed in this interval accounts for 92% of the total number of samples, and the peak range of concentration is between 4% and 10% (**Figure 4(b)**).

4.3. Reservoir Pore Type

Based on the results of previous cast thin section identification in the nearby blocks of the study area and the statistics of a large number of cast thin section identification results in the study area, it can be concluded as follows: the pore types of Chang 2 reservoir in the study area have various types, which can be divided into primary pores and secondary pores according to their development and growth history (Zhu et al., 2022). The residual intergranular pores in primary pores are the main ones, followed by intergranular dissolved pores in secondary pores, and a small number of mold holes (**Figure 5**).

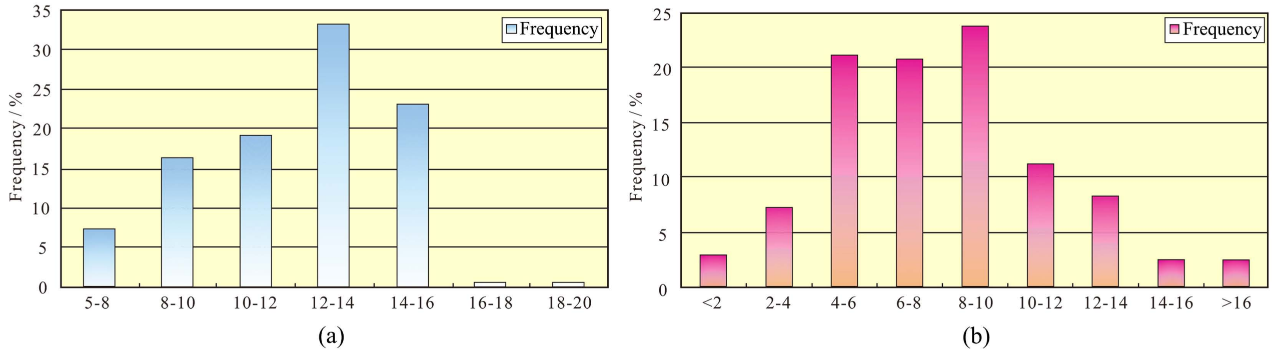

Figure 4. Frequency distribution of reservoir physical properties. (a) Frequency distribution of Chang 2^1 reservoir porosity; (b) Permeability frequency distribution map of Chang 2^1 reservoir.

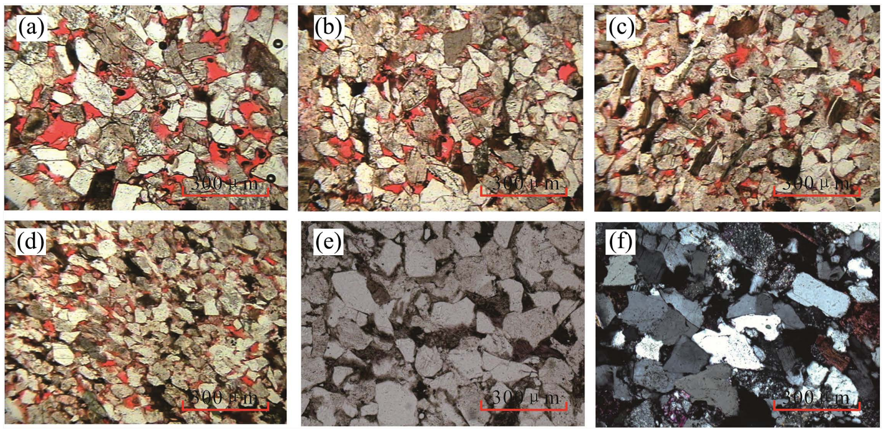

Figure 5. Reservoir space characteristics of Chang 2 formation in the study area. (a) well Z1, intergranular hole, solution hole, mold hole, expansion hole, 814.93 m, (−); (b) Well Z2, intergranular hole, mold hole, expanding hole, feldspar solution hole, 817.28 m, (−); (c) Well Z1, intergranular pore, intergranular solution pore, solution pore, 822.61 m, (−); (d) Well Z1, porphyritic hole, 819.24 m, (−); (e) Z2 well, mud-containing medium to fine-grained arspathic sandstone, the surface is concentrated with white titanium ore and other heavy minerals, and the shale filling pores densify the sandstone, 816.34 m, (+); (f) Z3 well, medium to fine grained arkose sandstone, significant increase in quartz, granular indenting contact, 818.34 m, (+).

5. Analysis and Discussion

5.1. Parameter Selection of Reservoir Division

There are many factors affecting the reservoir, but not all of them play a major role in the relevant study area. Therefore, when selecting favorable evaluation parameters, we should take the actual situation as the basis, instead of blindly selecting all the influencing factors, which not only increases the research burden, but also takes many detours. Therefore, the selection of parity parameters should be based on the size of the influence on the reservoir in the study area, and the parameters with high influence and strong correlation should be selected as the evaluation basis (He & Ren, 2016; Fang et al., 2023).

According to the actual situation in this study area, the main evaluation parameters selected include: permeability, porosity, displacement pressure, median pressure, maximum pore radius throat, median radius, throat mean value of pores, throat combination of pores, etc. According to the reservoir lithology, physical property, sensitivity and sedimentary characteristics studied above, the comprehensive reservoir classification evaluation is carried out in this area.

Disadvantages of the selected parameters: 1) These parameters are usually obtained by conventional logging methods or core tests, subject to the limitations of logging methods and sampling conditions as well as test conditions, and their accuracy and reliability may be affected; 2) These parameters are usually measured under static conditions and cannot fully reflect the dynamic characteristics of the reservoir. In the reservoir, the variation of fluid pressure, formation hydration grade and other factors may affect the reservoir properties.

Therefore, in order to evaluate the reservoir more comprehensively, objectively and accurately, the accuracy of the data was repeatedly verified based on the geological characteristics in this evaluation, and only static evaluation could be done due to the constraints of conditions.

5.2. High Quality Reservoir Division

According to the classification and rating standard of Mesozoic sandstone reservoirs in Ordos Basin proposed by Professor Zhao Jingzhou (Zhao et al., 2007), the Chang 2 reservoir in the study area is classified and evaluated.

Reservoirs of Yanchang Formation in Zichang area can be divided into 5 categories, which are as follows:

Class I medium high permeability layer: It is mainly distributed in the middle and upper reaches of rivers in the delta plain, mainly composed of clastic rocks, poor mineral particle roundness, large porosity and large throat channels. Its permeability is greater than 100×10^{-3} μm^2, porosity is greater than 20%, drainage pressure is less than 0.03 MPa, and median pressure is less than 0.19 MPa. The maximum pore roar radius is greater than 24.76 μm, the median radius is greater than 4.04 μm, and the mean pore roar is greater than 6.06 μm. This type is rare in the study area.

Class II low permeability layer: This type is subdivided into two subclasses II_a and II_b; It is mainly distributed in the middle and lower reaches of rivers in the delta plain, mainly composed of fine-grained clastic rocks and coarse-grained sandstones. The mineral particles have poor roundness, large-medium porosity and coarse throat channels. The permeability is $(100 - 10) \times 10^{-3}$ μm^2, the porosity is 20% - 15%, and the drainage pressure is 0.03 - 0.11 MPa. The median pressure is 0.19 - 0.68 MPa, the maximum pore roar radius is 24.76 - 7.05 μm, the median radius is 4.04 - 1.10 μm, and the mean pore roar is 6.06 - 1.77 μm. This type is more common in the study area.

Class III ultra-low permeability layer: This type is subdivided into two subclasses IIIa and IIIb; In this area, they are mainly distributed in the middle and upper reaches of braid rivers in the proto-delta, mainly in medium and fine-grained sandstone, with moderate particle roundness, medium-fine porosity and medium throat channel. Their permeability is $(10 - 1) \times 10^{-3}$ μm^2, porosity is

Table 1. Reservoir classification evaluation table of rock research area.

	II_a	II_b	III_a	III_b	IV_a
Ratio of corresponding reservoir volume to total reservoir volume (%)	1.1	23.7	54.8	19.6	0.8

15% - 11%, and displacement pressure is 0.11 - 0.37 MPa. The median pressure is 0.68 - 2.49 MPa, the maximum pore roar radius is 7.05 - 2.01 μm, the median radius is 1.10 - 0.30 μm, and the mean pore roar is 1.77 - 0.52 μm. This class is common in the study area.

Class IV ultra-low permeability layer: This class is subdivided into two subclasses IV a and IV b; In this area, it is mainly distributed in the middle and lower reaches of braided rivers in the proto-delta area, mainly in the form of fine-granular sandstone, with good mineral particle roundness, small-fine porosity and small throat channels. Its permeability is $(1 - 0.2) \times 10^{-3}$ μm^2, porosity is 11% - 7%, and displacement pressure is 0.37 - 1.31 MPa. The median pressure is 2.49 - 9.10 MPa, the maximum pore roar radius is 2.01 - 0.57 μm, the median radius is 0.30 - 0.08 μm, and the mean pore roar is 0.52 - 0.15 μm. This class is uncommon in research.

Class V dense layer: In this region, siltstone and shale are mainly distributed in the pre-delta zone, with small mineral particles, high shaliness content, fine-micro-porosity, micro-fine throat- micro-throat, with permeability less than 0.1×10^{-3} μm^2, porosity less than 7%, drainage pressure greater than 1.31 MPa, and median pressure greater than 9.10 MPa. The maximum pore roar radius is less than 0.57 μm, the median radius is less than 0.08 μm, and the mean pore roar is less than 0.15 μm. This species is almost absent in the study area.

The Chang 2 member reservoir is mainly Class III_a, which accounts for 54.8%, followed by class II_b and III_b, which account for 23.7% and 19.6% respectively (**Table 1**). III_a, II_b and III_b are the main reservoirs, and the total proportion of these three can reach 98.1%. It can be concluded that the Chang 2 member of the sub-study area is mainly dominated by ultra-low porosity and low permeability reservoirs and low porosity and low permeability reservoirs.

6. Conclusion

Chang 2_1^1 was braided river deposit in geological history, and the scale of the sedimentary channel was small. Chang 2_1^2 was braided river deposit in geological history, and Chang 2_1^3 was braided river sand bar deposit in geological history.

The reservoirs in Chang 2 member of the study area are dominated by III_a, II_b and III_b, and the reservoirs are mainly dominated by ultra-low porosity and low permeability reservoirs and low porosity and low permeability reservoirs. Next, it is necessary to further carry out geological exploration to understand the distribution characteristics and change laws of the reservoir, so as to provide more comprehensive data for the exploration and development of oil and gas resources. It is recommended to take targeted development measures according to the type and characteristics of the reservoir, such as optimizing drilling and exploitation technology, strengthening water injection, etc., to improve the recovery rate.

Conflicts of Interest

The authors declare no conflicts of interest.

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