

Hydrocarbon Accumulation Characteristics of Chang 2 Reservoir in Eastern Xiaohe, Jingbian Oilfield, Ordos Basin, China

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Abstract

Using hydrocarbon geochemistry, reservoir properties and oil test data, we have studied the oil source conditions, reservoir characteristics, age of formation and oil and gas enrichment rules of the Chang 2 reservoir in the eastern part of Xiao he of the Jingbian Oilfield by using common thin section and fluid inclusions and other technical methods. The results of the study show that: the eastern part of Xiao he area develops Chang 7 high-quality hydrocarbon source rock, its organic carbon is 2.20% on average, the type of organic matter is I-II₁ type which is mainly oil-generating, and has reached the stage of a large amount of oil-generating, which can provide the material basis for the formation of the Chang 2 oil reservoir. The physical properties of the Chang 2 reservoir are relatively good, and the reservoir capacity is strong. The type of Chang 2 reservoir is tectonic-lithological composite reservoir; the temperature measurement of reservoir fluid inclusions shows that the reservoir was mainly formed in the middle and late Early Cretaceous period, and the time is about 115 Ma; the distribution and enrichment of the Chang 2 reservoir are mainly controlled by the integrated control of the storage cap layer and the physical properties of the reservoir.

Keywords

Chang 2, Reservoir, Accumulation Rule, The Eastern Part of Xiaohe

1. Introduction

Ordos Basin is one of the most important oil and gas basins in China. Its oil and gas resources are mainly concentrated in the Upper Triassic Yanchang Formation,

followed by the Lower Jurassic Yan'an Formation. The Yanchang Formation is subdivided into 10 oil layer groups, from Chang 1 to Chang 10, of which Chang 2 is one of the main oil producing layers, which can be subdivided into three oil layer subgroups: Chang 2₁, Chang 2₂ and Chang 2₃ (Wang & Wu, 2007). The previous research results show that the delta plain deposits are mainly developed in the Chang 2 period, and the distributary channel is the main reservoir sand body. The oil source is mainly from the Chang 7 high-quality source rock in the central part of the Yanchang Formation lake basin. Due to the relatively long distance between the Chang 2 reservoir and the oil source, its hydrocarbon supply capacity is limited, so the Chang 2 reservoir shows the characteristics of low oil saturation (Yuan et al., 2017). The Chang 2 reservoir is mainly a structural-lithologic composite reservoir, which is one of the main producing reservoirs in Jingbian Oilfield. However, there is a lack of systematic research on the oil source and accumulation characteristics of the Chang 2 reservoir in the past (Xie et al., 2017). Taking the Chang 2 reservoir in the east of Xiaohe as an example, according to the relevant data, this paper summarizes the accumulation characteristics of Chang 2 reservoir from the aspects of source rock conditions, reservoir characteristics, accumulation age and enrichment law, so as to provide geological basis for oil exploration in this area.

2. Source Rock Characteristics

2.1. Distribution Characteristics

The lithology of source rocks in Yanchang Formation of Ordos Basin is black shale and dark mudstone, mainly black shale (Zhong et al., 2016). The hydrocarbon generation center of the basin is located in the southwest of the whole basin, and the hydrocarbon generation potential energy is large. The east of Xiaohe is located in the northeast of the basin, far away from the hydrocarbon generation center, and the hydrocarbon generation potential energy is low. However, after the hydrocarbon generation of the source rock, the oil and gas will migrate from the part with high hydrocarbon generation potential energy to the part with low hydrocarbon generation potential energy. Therefore, it is considered that the oil and gas in the study area come from the source rock of the bottom Yanchang Formation (Zhang et al., 2020).

The distribution area of effective source rocks in Chang 7 is 2.34×10^4 km². The thickness of effective source rocks is more than 160 meters, and the average cumulative thickness is about 60 meters. The vitrinite reflectance R_o is greater than 0.8%. The evolution of source rocks has entered a mature stage. The total hydrocarbon generation of source rocks is 2251.17×10^8 t, and the total hydrocarbon expulsion is 1125.58×10^8 t. It has sufficient oil source and great potential for oil and gas resources (Liu et al., 2015) (Figure 1).

2.2. Maintaining the Integrity of the Specifications

Through the analysis of geochemical test data of Chang 7 source rocks in the study

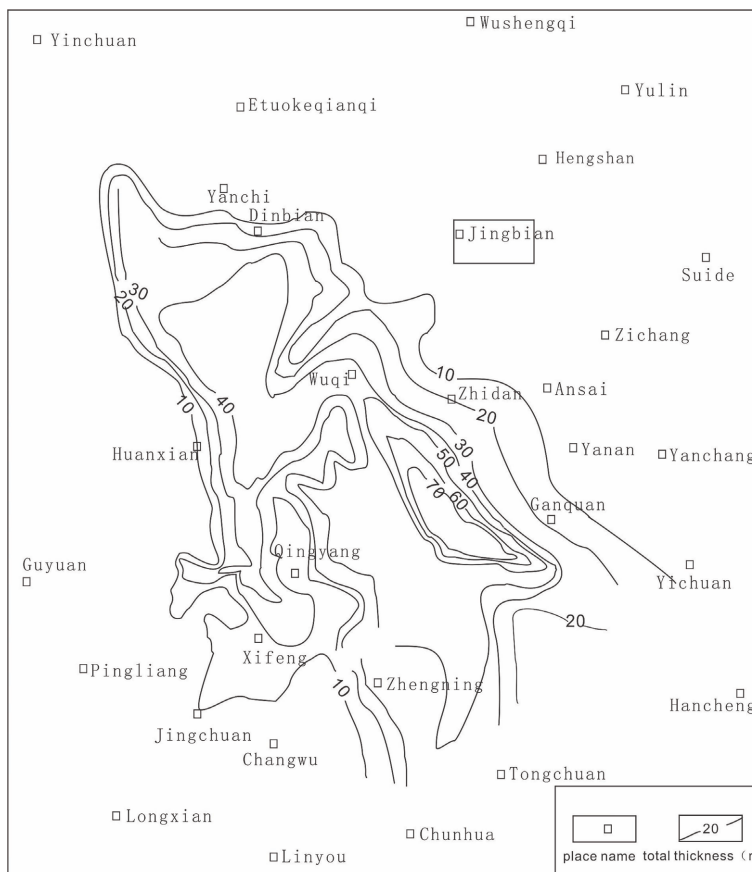


Figure 1. Contour map of source rock thickness in Ordos Basin geochemical characteristics.

area, it is found that the main peak distribution range of total organic carbon content (TOC) of Chang 7 shale is between 1% and 3%, with an average content of 2.20%. The main distribution range of hydrocarbon generation potential ($S_1 + S_2$) is between 5 - 15 mg/g, and the average content is 15.8 mg/g. The content of chloroform asphalt “A” is 0.1% - 0.4%, with an average content of 0.23% (Figures 2-4).

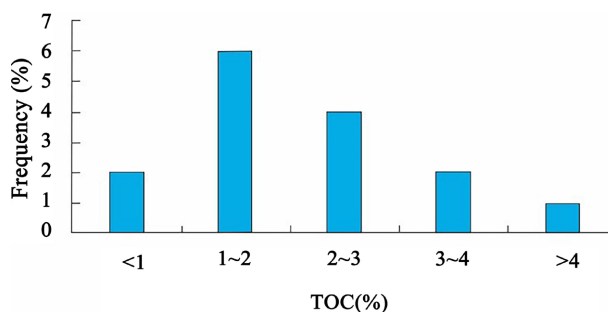


Figure 2. TOC frequency distribution of Chang 7 shale in eastern Xiaohu area.

The macerals of organic matter in the Chang 7 shale in the study area are mainly sapropelic group and exinite group, accounting for up to 95%, and the content of

vitritinite and inertinite is low. Through the statistics of microscopic macerals, it is found that the Chang 7 shale is mainly composed of I-II₁ kerogen (Figure 5), which has strong oil generation capacity (Zhao et al., 2007).

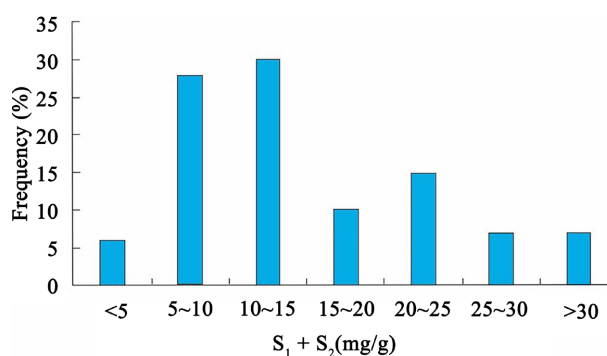


Figure 3. S₁ + S₂ frequency distribution map of Chang 7 shale in eastern Xiaoho area.

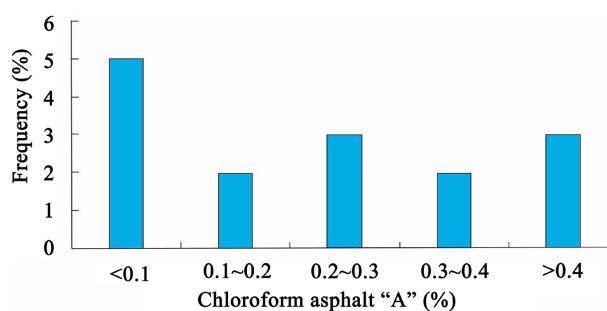


Figure 4. The frequency distribution of chloroform asphalt "A" in Chang 7 shale in the eastern part of Xiaoho River.

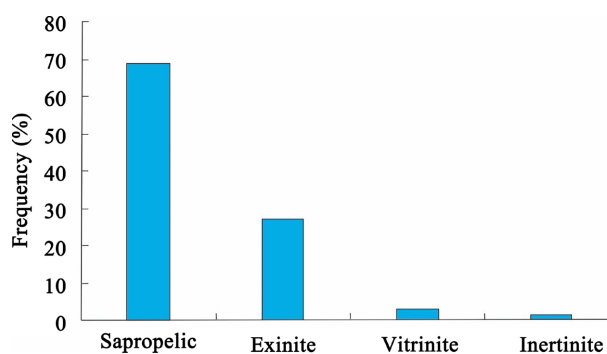


Figure 5. Comparison of kerogen microscopic composition of Chang 7 source rocks in the eastern part of Xiaoho River.

The highest pyrolysis peak temperature (T_{\max}) is an effective indicator of maturity. The T_{\max} value of Chang 7 shale is distributed at 439°C - 454°C, which has reached the peak evolution stage of oil generation. The vitritinite reflectance is 0.56% - 1.41% (Table 1), reflecting that the Chang 7 source rock has reached the high oil generation stage.

Table 1. Maturity index table of Chang 7 source rocks in eastern Xiaohe area.

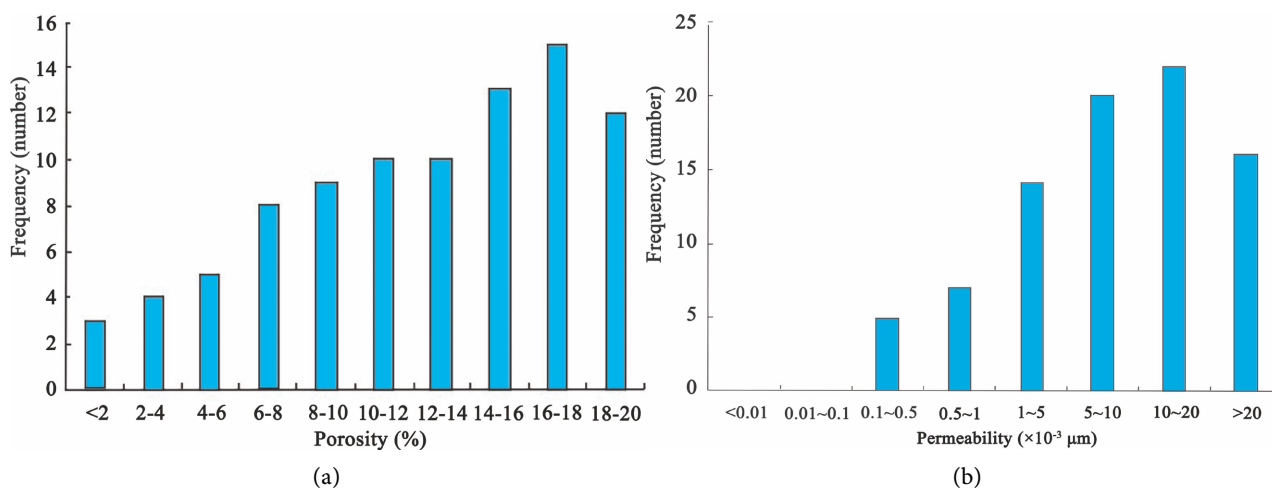
Horizon	Vitrinite reflectance Ro (%)		OEP		Rock pyrolysis T _{max} (°C)		maturity stage
	variation range	average	variation range	average	variation range	average	
Chang 7	0.56 - 1.41	0.90	1.05 - 1.13	1.09	439 - 454	449	mature

Therefore, based on the characteristics of organic matter abundance, type and thermal evolution degree of source rocks, the Chang 7 shale in the study area is a high-quality source rock.

3. Reservoir Physical Properties and Pore Structure Characteristics

3.1. Physical Characteristics of Chang 2 Reservoir

The core porosity and permeability test of Chang 2 reservoir in the study area shows that the porosity of the reservoir is distributed between 1.67% and 19.43%, the average porosity is 12.41%, the main porosity is between 16% and 18%, the maximum permeability is $10.01 \times 10^{-3} \mu\text{m}^2$, and the minimum permeability is $0.1 \times 10^{-3} \mu\text{m}^2$. The permeability distribution range is between $5 \times 10^{-3} - 20 \times 10^{-3} \mu\text{m}^2$, and the average permeability is $10.01 \times 10^{-3} \mu\text{m}^2$, which is comprehensively evaluated as an ultra-low permeability reservoir (Figure 6).

**Figure 6.** Histogram of porosity and permeability distribution of Chang 2 reservoir in the east of Xiaohe.

3.2. Pore Structure Characteristics of Chang 2 Reservoir

By analyzing the pore types of Chang 2 reservoir, it is considered that the pore types of Chang 2 reservoir are mainly residual intergranular pores, followed by dissolution pores, and feldspar dissolution pores and debris dissolution pores are the main pore types (Figure 7). The high pressure mercury injection data show that the displacement pressure of Chang 2 reservoir is 1.82 MPa, the saturated median pressure is 41.40 MPa, the maximum throat radius is $0.40 \mu\text{m}$, the median throat radius is $0.02 \mu\text{m}$, the mercury removal efficiency is 36.05% (Figure 8), and

the maximum mercury saturation is 84.24% (Bai et al., 2010; Feng et al., 2020; Bai et al., 2013; Zhao et al., 2020). It is concluded that the displacement pressure of Chang 2 reservoir in the study area is low, which is good-medium, and the mercury removal efficiency is high, which shows that the reservoir storage and seepage are good.

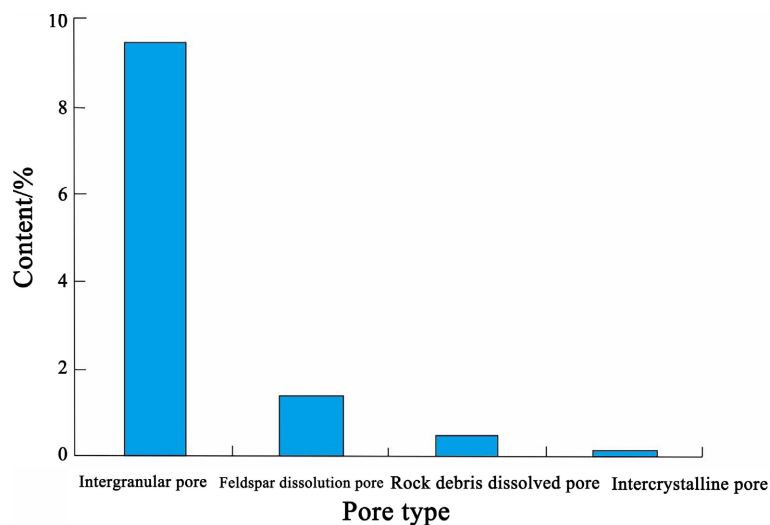


Figure 7. Pore type diagram of Chang 2 reservoir in eastern Xiaohe area.

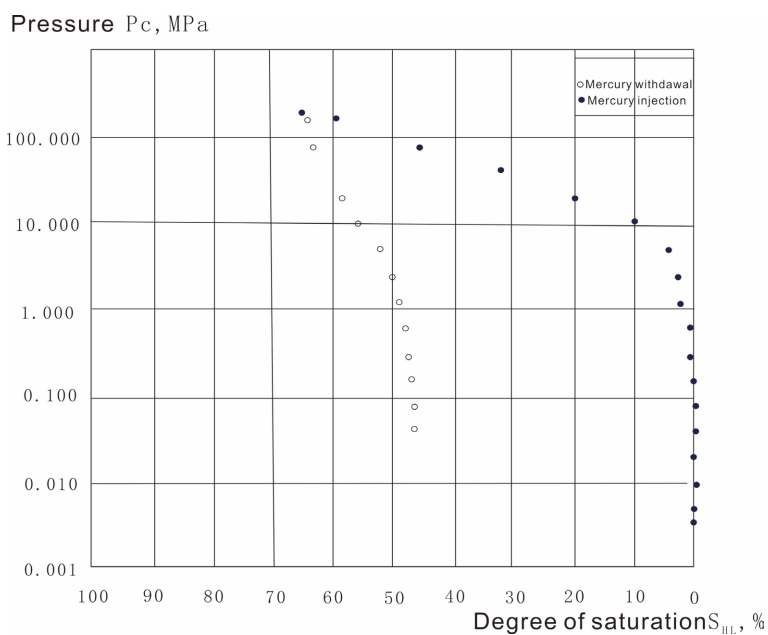


Figure 8. Pore type diagram of Chang 2 reservoir in eastern Xiaohe area.

4. Reservoir Characteristics

4.1. Reservoir Characteristics and Reservoir Types

Based on the reservoir pressure, formation temperature test data and regional research results in the study area, the geothermal gradient is determined to be

2.9°C/100m, the pressure coefficient of Chang 2 reservoir is 0.87, the average density is 0.8678 g/cm³, the average viscosity is 12.1 mPa·s, and the average freezing point is 16.64°C, which belongs to light and medium viscosity crude oil (Lin et al., 2017; Wang et al., 2002; Zhao et al., 2022; Shao et al., 2023).

The oil layer is mainly distributed in the channel sand body of the Chang 2₂ oil layer sub-group, which has good plane continuity and is distributed along the distribution direction of the channel sand body. The oil and gas enrichment is mainly controlled by the factors such as the nose-like uplift structure, the distribution of the top cap rock and the lateral lithologic barrier. The reservoir type is mainly a structural-lithologic composite reservoir (Figure 9).

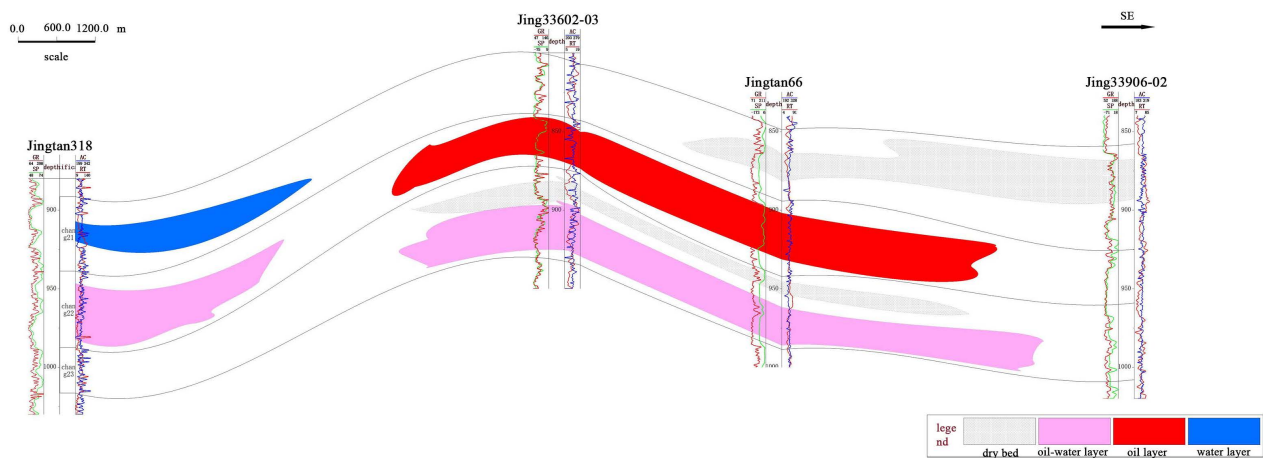


Figure 9. Oil-water distribution characteristics of Chang 2 reservoir in eastern Xiaohé area.

4.2. Accumulation Age

There are mainly two types of liquid brine inclusions and liquid hydrocarbon inclusions in Chang 2 reservoir minerals (Figure 10), which are mainly distributed in quartz microcracks. The size of inclusions is generally 3 - 6 μm, and the gas-liquid ratio is mostly distributed in 5% - 20%. The research shows that the homogenization temperature of the brine inclusions associated with hydrocarbon inclusions ranges from 70°C to 130°C, showing a continuous single peak distribution, and the main peak is distributed between 90°C and 110°C (Figure 11) (Sun et al., 2022).

Fluid inclusions trapped in mineral-defective caverns are direct evidence of paleofluid filling. On this basis, through the determination of the homogenization temperature of the brine inclusions associated with hydrocarbon inclusions, combined with the burial-thermal evolution history diagram (Figure 12), the specific time of inclusion capture is determined, which is the time of oil and gas accumulation (Chen et al., 2007). Through the PetroMod oil and gas system numerical simulation software, the burial-thermal evolution history of the Chang 2 reservoir was restored. The oil and gas filling of the reservoir was a continuous accumulation period of about 115 Ma, which was in the middle and late Early Cretaceous (Shi et al., 2014).

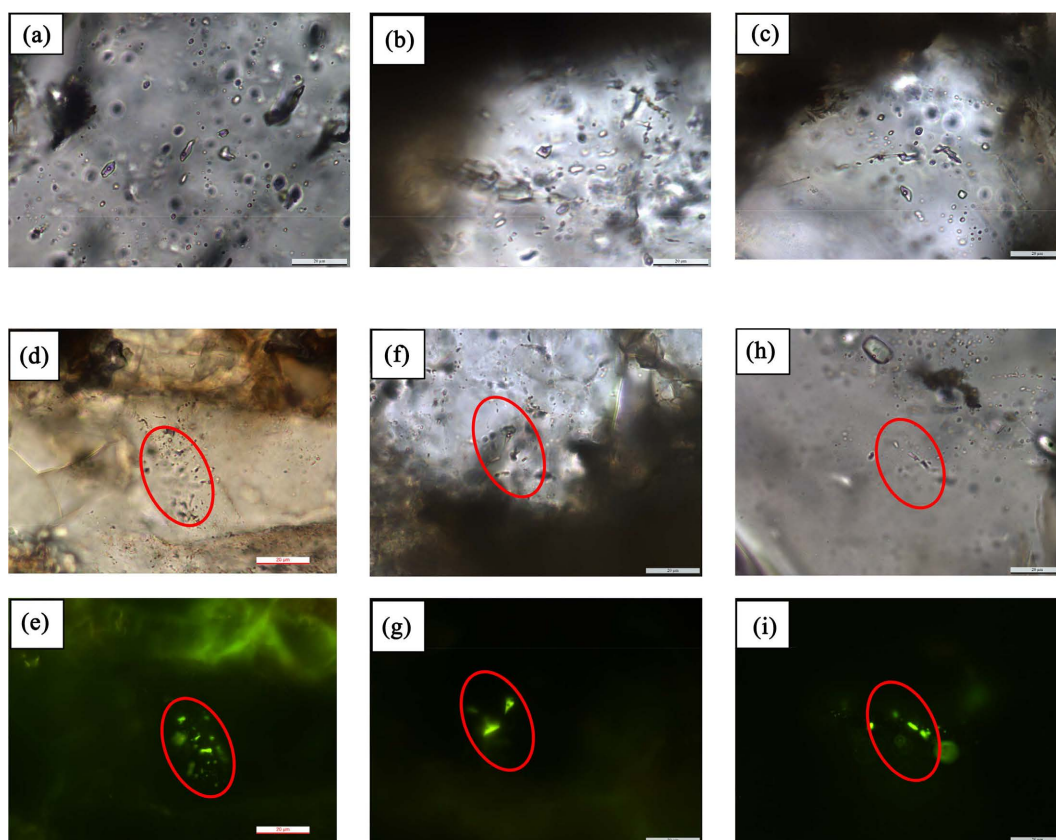


Figure 10. Characteristics of Chang 2 fluid inclusions in eastern Xiaohe area.

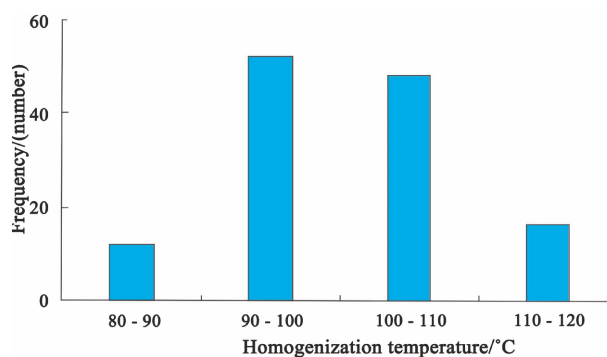


Figure 11. Homogenization temperature histogram of fluid inclusions in Chang 2 of eastern Xiaohe area.

4.3. Enrichment Regularity

Reservoir conditions have an important influence on the distribution and enrichment of Chang 2 reservoir. After compaction, pressure solution and cementation, the original pores of Chang 2 reservoir in the study area are significantly reduced. However, due to the deep burial depth of Chang 2 reservoir group, the content of feldspar and debris in sandstone composition is higher than that of Yan'an formation sandstone, and the porosity of reservoir changes significantly after diagenesis. Therefore, the development degree of residual intergranular pores and dissolution pores directly affects the permeability of reservoir (Xun et al., 2016).

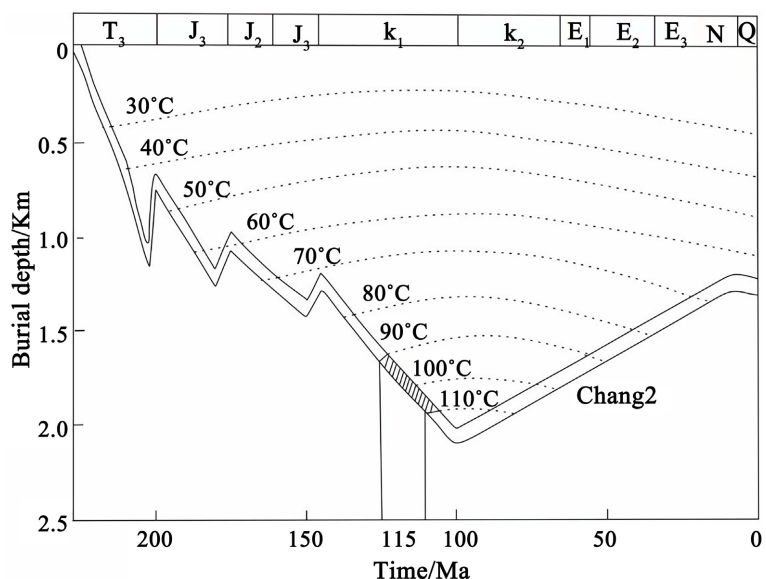


Figure 12. Burial-thermal evolution history and accumulation time of Chang 2 reservoir group in eastern Xiaohe area.

The delta plain deposits are developed in the study area of Chang 2, and the channel sand bodies are superimposed in multiple periods. The vertical cumulative thickness can reach 30.63 m, and the average sand-to-ground ratio is 0.63 (Table 2), which provides favorable conditions for the formation of Chang 2 reservoir. The thickness of Chang 2 sandstone in the study area is large, and it is easy to form compaction structure by differential compaction. Nasal uplift is formed in the sand body development zone. The center of the sand body is often the highest part of the uplift. If there is lithologic occlusion in the upward direction, structural-lithologic reservoirs can be formed (Wang et al., 2019).

Table 2. Maturity index table of Chang 7 source rocks in eastern Xiaohe area.

Horizon	Average thickness of strata (m)	Average thickness of sand layer (m)	sand ratio
Chang 2 ¹	48.40	29.78	0.62
Chang 2 ²	47.50	29.84	0.63
Chang 2 ³	49.70	32.27	0.65
Chang 2	48.53	30.63	0.63

5. Conclusion

1) The Chang 7 shale of Yanchang Formation in the east of Xiaohe is widely distributed, with high abundance of organic matter and good type. It has reached the peak of oil generation, forming high-quality source rocks and providing oil source for the formation of Chang 2 reservoir.

2) Chang 2 reservoir is a structural-lithologic composite reservoir. Through the fluid inclusion test method, combined with the burial-thermal evolution history,

it is determined that the Chang 2 reservoir is a stage of accumulation, and the formation time is 115 Ma, which is the middle and late stage of early Cretaceous.

3) Nasal uplift structure, reservoir continuity and reservoir physical properties are the main factors controlling the distribution and enrichment of Chang 2 reservoir. The focus of future exploration should be based on the coupling area of the main controlling factors of reservoir formation, and the main goal is to find favorable traps.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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