Analysis of Differences and Main Controlling Factors of the Chang 8 Reservoir in the Longdong-Jiyuan Area

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Abstract

Although the Chang 8 reservoir in the Ordos Basin holds significant resource potential as a crucial exploration and development interval, existing research has primarily focused on regional geological patterns, with limited systematic analysis of reservoir characteristics and production performance. To address this gap, this study investigates the Longdong and Jiyuan areas by integrating data on petrological characteristics, physical properties, pore structures, percolation features, and production performance. A systematic comparison of reservoir differences between the two regions was conducted, and the grey correlation method was employed to identify the main controlling factors influencing development performance. The results indicate that the Longdong area has a relatively simple sediment source, with lithologies dominated by lithic feldspathic sandstones. The interstitial materials are primarily chlorite, which aids in preserving primary intergranular pores, resulting in an ultra-low permeability reservoir overall. In contrast, the Jiyuan area, influenced by multiple sediment sources, exhibits complex rock types with higher kaolinite content in interstitial materials and well-developed feldspar dissolution pores, yet it displays even lower permeability, classifying it as a super-low permeability reservoir. Regarding pore structure, the Longdong area features a favorable pore-throat configuration, characterized by low displacement pressure and good connectivity, whereas the Jiyuan area is dominated by fine pore throats with complex structures. Water flooding experiments reveal that although the Jiyuan area demonstrates higher oil displacement efficiency during both the anhydrous period and the final stage, it experiences a higher decline rate and slightly lower initial production compared to the Longdong area. Grey correlation analysis shows that the main controlling factors for initial productivity are intergranular pores, maximum mercury saturation, and porosity; for the decline rate, the key factors include final oil displacement efficiency, feldspar dissolution pores, injection pore volume multiples, and porosity. Comprehensive analysis suggests that differences in sediment sources control the reservoir rock and pore compositions, thereby influencing percolation capacity and development response characteristics. These findings provide a theoretical basis for efficient development and precise regulation of Chang 8 reservoirs.

Keywords

Ordos Basin; Chang 8 Reservoir; Reservoir Characteristics; Development Performance; Grey Correlation Analysis; Main Controlling Factors.

1. Regional Geological Setting

Influenced by the Indosinian movement, the lacustrine basin during the Yanchang Period experienced a complete evolutionary cycle of expansion, culmination, and demise. Specifically, from the Chang 10 to Chang 7 intervals, the lake basin continuously expanded and reached its peak, while after the Chang 6 interval, it gradually shrank and eventually disappeared. The Chang 8 interval represents a period of lake basin expansion, characterized by relatively rapid sediment accumulation, with the primary depositional environment being a shallow-water delta. The Chang 8 reservoir interval is further subdivided into two sub-members, with lithologies generally comprising siltstone, fine sandstone, and medium sandstone[1][2][3][4]. The thickness of the Chang 8 reservoir ranges approximately from 40 to 80 meters. The main producing interval in the study area is the Chang 8_1 member, which consists of deposits from the delta front subfacies, with the predominant sedimentary microfacies being underwater distributary channels. Sediment sources are primarily derived from three major directions: northeast, northwest, and southwest. Sand bodies, mainly deposited as underwater distributary channel sands, serve as the primary reservoir spaces, exhibiting good lateral continuity and significant thickness. However, the reservoir physical properties are relatively poor, classifying it as a low-permeability reservoir. Hydrocarbon sources are primarily derived from the overlying Chang 7 source rocks, representing a near-source accumulation model characterized by upper generation and lower storage.

2. Reservoir Petrological Characteristics

Statistical analysis of 135 thin section samples from the Chang 8 reservoir in the Longdong-Jiyuan area indicates that the sandstone types in the study area are predominantly lithic feldspathic sandstone, followed by feldspathic lithic sandstone and feldspathic sandstone. Among the detrital components of the reservoir sandstones, quartz exhibits the highest content, ranging from 26.88% to 55.65%, with an average of 33.31%. Feldspar content is secondary, ranging from 11.43% to 40.41%, with an average of 23.61%. Rock fragments show the lowest content, ranging from 12.64% to 28.46%, with an average of 21.23%. The detrital grain size is mainly fine to medium-grained, followed by very fine to fine-grained, with sorting predominantly moderate to well, as illustrated in Fig. 1.

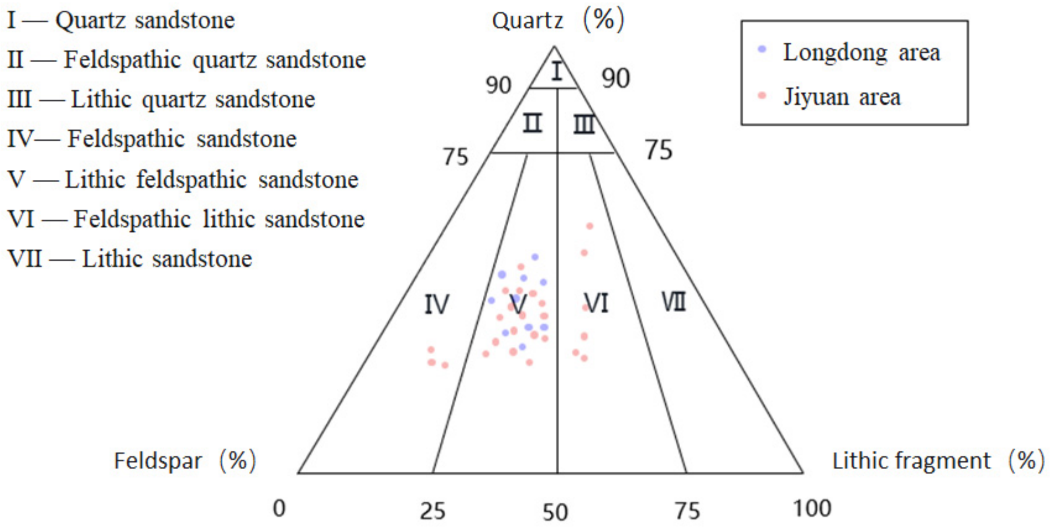


Fig 1. Ternary diagram showing sandstone classification of the Chang 8 reservoir in the Longdong-Jiyuan area

Scanning electron microscopy (SEM) and X-ray diffraction (XRD) analysis of clay minerals indicate that the interstitial material content in the Chang 8 reservoir of the Longdong-Jiyuan area ranges from 10% to 15%, averaging 12.56%. These interstitial materials consist predominantly of clay minerals and carbonate minerals, with the Jiyuan area containing 1.2% siliceous minerals. The interstitial material content in the Chang 8 reservoir of the Longdong area is higher than that of the Jiyuan area, at 13.2% and 10%, respectively. In the Longdong area, chlorite content is relatively high, approximately 6%, followed by kaolinite at 1.6%. Chlorite coatings inhibited the authigenic enlargement of quartz and, to some extent, mitigated the damage of compaction on reservoir physical properties, thereby favoring the preservation of primary intergranular pores. In the Jiyuan area, kaolinite exhibits the highest content among interstitial materials, approximately 4%, followed by calcite, ferroan calcite, and chlorite, indicating the presence of strong dissolution during the diagenetic period in this area.

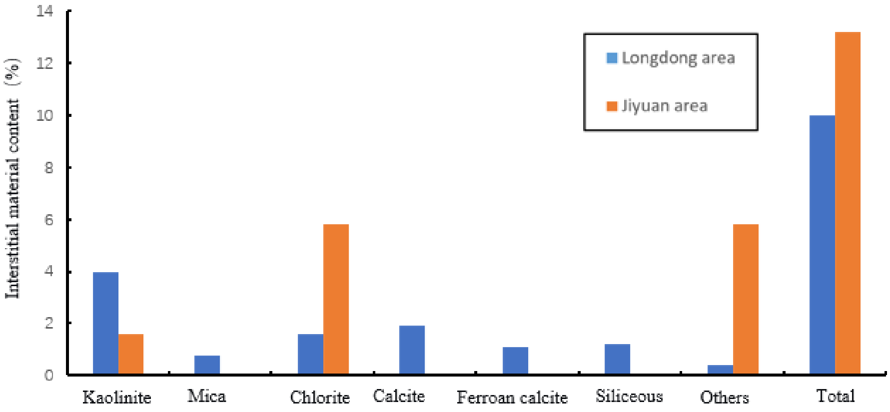


Fig 2. Frequency histogram of interstitial material distribution in the Chang 8 reservoir, Longdong-Jiyuan area

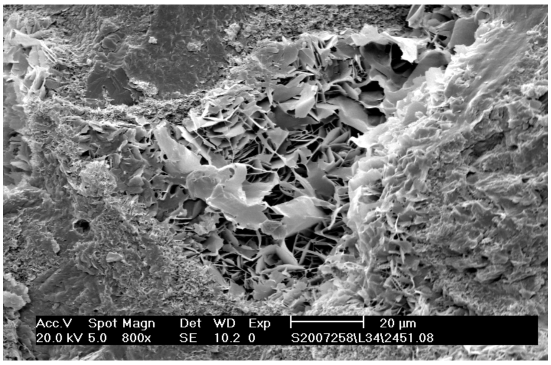


Fig 3. Intergranular distribution of foliated chlorite (Longdong area)

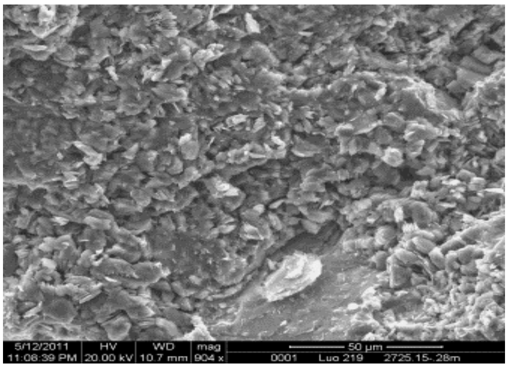


Fig 4. Pervasive kaolinite filling resulting in an overall dense texture (Jiyuan area)

3. Reservoir Characteristics

3.1. Reservoir Space Characteristics

The primary pore types in the Chang 8 reservoir of the Longdong-Jiyuan area include intergranular pores, feldspar dissolution pores, lithic fragment dissolution pores, matrix dissolution pores, intercrystalline pores, and microfractures, with an average surface porosity of 4.5%, as shown in Fig. 4.

Intergranular pores and feldspar dissolution pores are commonly developed in the Chang 8 reservoir of the Longdong-Jiyuan area. The intergranular pore contents are 54.05% and 51.49%, respectively, while the feldspar dissolution pore content in the Jiyuan area is higher than that in the Longdong area, at approximately 39.51% and 29.72%, respectively. These pore types constitute the most important spaces for hydrocarbon accumulation in the study area. Honeycomb-like feldspar dissolution pores were observed under scanning electron microscopy.

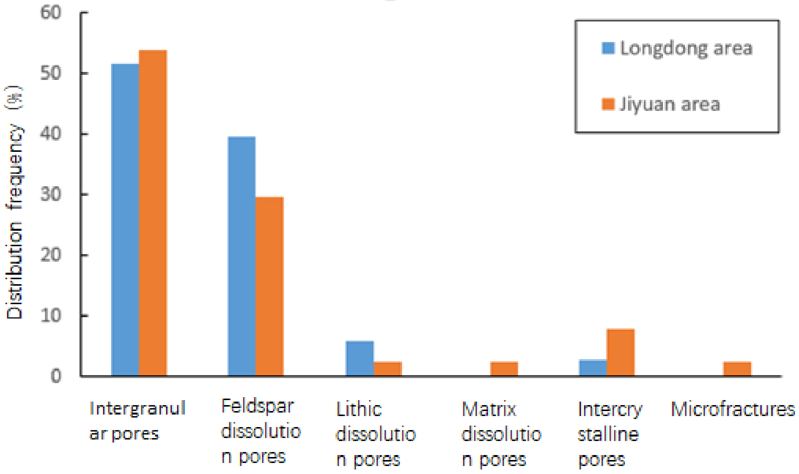
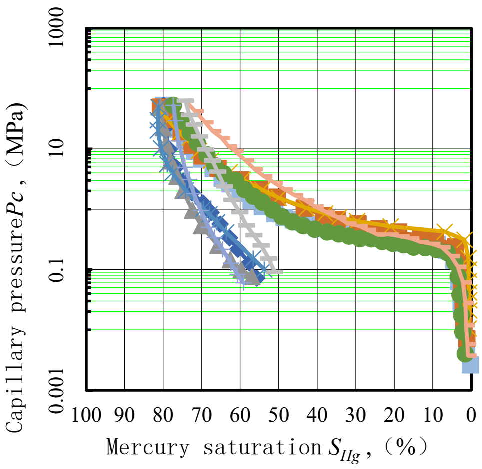


Fig 5. Distribution frequency of pore types in the Chang 8 reservoir in the Longdong-Jiyuan area

3.2. Pore Structure

By observing the morphology of mercury injection capillary pressure curves from 10 sandstone samples of the Chang 8 reservoir in the Longdong-Jiyuan area, it was found that the slope of the gentle section of the mercury injection curve in the Longdong area is smaller than that in the Jiyuan area, indicating better connectivity in the Jiyuan area, while also suggesting the presence of larger pore throats in the samples from the Longdong area.



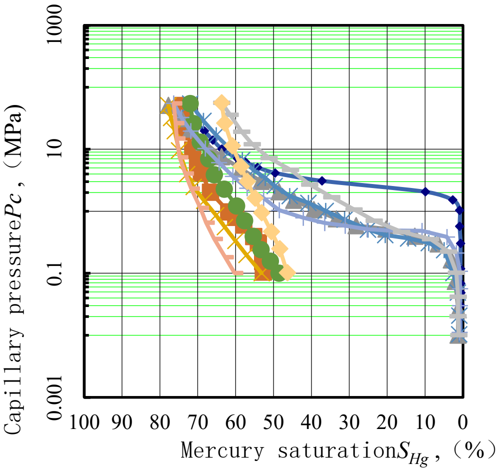


Fig 6. Mercury intrusion curves of Chang 8 reservoirs in the Longdong area

Fig 7. Mercury intrusion curves of Chang 8 reservoirs in the Jiyuan area

Mercury injection experiments conducted on 10 sandstone samples from the Chang 8 reservoir in the Longdong-Jiyuan area reveal that the average displacement pressure in the Longdong area is higher than that in the Jiyuan area, at 1.56 MPa and 0.62 MPa, respectively. The median pressure in the Longdong area is lower than that in the Jiyuan area, at 3.51 MPa and 11.32 MPa, respectively. The maximum mercury saturation shows little difference between the two areas, while the mercury ejection efficiency in the Longdong area is higher than that in the Jiyuan area, at 31.29% and 24.66%, respectively.

Overall, the capillary pressure parameters of the Chang 8 reservoir in the Longdong area are characterized by relatively low displacement pressure and median pressure, larger median radius, higher maximum mercury saturation, better pore-throat structure, and good connectivity between pores and throats. In contrast, the Chang 8 reservoir in the Jiyuan area exhibits the highest displacement pressure and median pressure, the smallest median radius, and a relatively poor pore-throat structure.

3.3. Physical Property Characteristics

The Chang 8 reservoir is classified as a low-porosity, ultra- to super-low permeability reservoir, with porosity primarily ranging from 7% to 12% and permeability ranging from 0.2 to 1.5×10^{-3} μm^2. Specifically, the Jiyuan area is characterized as a super-low permeability reservoir, with a maximum porosity of 10.9%, a minimum porosity of 6.7%, and an average permeability of only 0.52×10^{-3} μm^2. In contrast, the Longdong area is predominantly an ultra-low permeability reservoir, with a maximum porosity of 11.6%, a minimum porosity of 8%, and an average permeability of 1.27×10^{-3} μm^2.

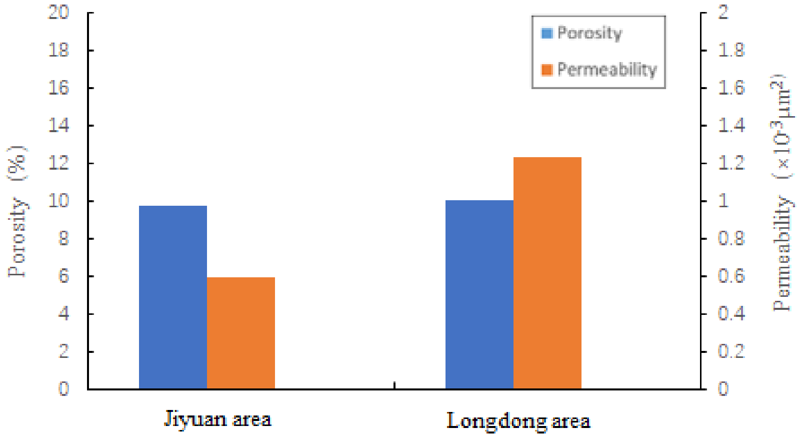


Fig 8. Physical properties of the Chang 8 reservoir in the Jiyuan-Longdong area

4. Development Status

Table 1. Decline characteristics of Chang 8 reservoir blocks in the Jiyuan-Longdong area

	Decline type	Decline type	Production-time relationship equation	Decline type	Decline rate after one year of production	Annual production after one year of production ($\times10^4$ t)
Jiyuan	Exponential type	0.9816	Q=1.8933e-0.0129 t	n=0	43.30%	3.0
Longdong	Exponential type	0.9281	Q=1.9127e-0.0037 t	n=0	34.40%	3.2

According to statistical analysis, the Jiyuan area exhibits characteristics of low initial production and high decline rate, with an annual initial production of 3.0×10^4 t. The Longdong area shows relatively higher initial production, with an annual initial production of 3.2×10^4 t, and also experiences a significant decline. Both the Jiyuan and Longdong areas follow an exponential decline pattern, with correlation coefficients of 0.9816 and 0.9281, respectively, and decline rates of 43.3% and 34.4% after one year of production.

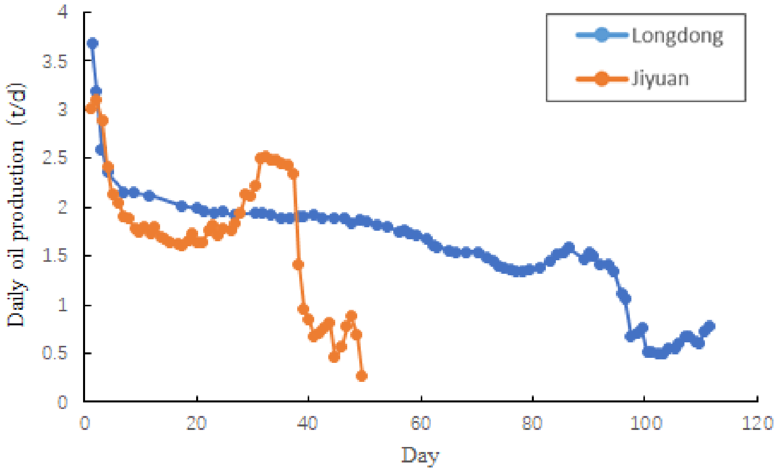


Fig 9. Changes in Average Single-Well Production of Chang 8 Oil Reservoirs in the Jiyuan-Longdong Area

5. Method for Determining Main Controlling Factors of Development Performance (Grey Correlation Method)

Through research and analysis of the geological conditions in the Longdong and Jiyuan areas, it is observed that numerous complex geological factors are involved in the development process, each exerting different degrees of influence. To accurately evaluate the impact of these factors, quantitative indicators related to each factor were selected, and mathematical methods were applied for quantitative analysis. This approach enables precise assessment of the development status of specific blocks and identification of the key factors governing development. The grey correlation method was employed to analyze the main controlling factors of the current development status in the Longdong and Jiyuan areas.

5.1. Basic Principles

The grey correlation method is a mathematical analysis approach based on multiple factors. It calculates the degree of grey correlation according to the relationships among various factors, thereby determining the strength, magnitude, and order of these relationships. Specifically, the higher the grey correlation degree between the main factor sequence and the behavioral factor sequences, the closer their relationship, and the greater the influence of the behavioral factor sequences on the main factor sequence.

5.2. Basic Steps

5.2.1. Determination of Analysis Sequences

The decline rate (or productivity, etc.) is designated as the reference sequence[6][7][8][9], expressed as:

$$X_0 = \{X(k)/k = 1,2,\cdots n\}$$

The selected influencing factors are designated as the comparison sequences, expressed as:

$$X_i = \{X_i(k)\ /\ k = 1,2,\cdots n\} i = 1,2,\cdots,m$$

Where n represents the number of time points within the time period, and m represents the number of influencing factors.

5.2.2. Dimensionless Processing of Sequences

Due to the different physical meanings, dimensions, and orders of magnitude of the parameters in the sequences, direct comparison is inconvenient and may lead to incorrect conclusions. Therefore, dimensionless processing is required. In this study, the initial value method is selected to obtain new sequences (Y_0, Y_1... Y_n) within the same comparative dimension. The calculation formula is:

$$Y(k) = \frac{X(k)}{X(1)}$$

Table 2. Sequence values of water breakthrough (water appearance) and influencing factor indicators for various oilfields in the Chang 8 reservoir

sequence	influencing factor	Jiyuan area	Longdong area	sequence	influencing factor	Jiyuan area	Longdong area
reference sequence	productivity	3	3.2	comparison sequence	intercrystalline pores	2.9	8.1
reference sequence	decline rate	43.3	34.4	comparison sequence	kaolinite	4	1.6
comparison sequence	displacement pressure (MPa)	1.56	0.62	comparison sequence	chlorite	1.6	5.8
comparison sequence	median pressure (MPa)	11.32	3.51	comparison sequence	calcite	1.9	0
comparison sequence	median radius (μm)	0.07	0.32	comparison sequence	ferroan calcite	1.1	0
comparison sequence	sorting coefficient	1.84	2.47	comparison sequence	siliceous material	1.2	0
comparison sequence	variation coefficient	0.15	0.23	comparison sequence	others	0.4	5.8
comparison sequence	maximum mercury saturation (%)	77.31	80.11	comparison sequence	total	10	13.2
comparison sequence	mercury ejection efficiency (%)	24.66	31.29	comparison sequence	porosity	9.8	10
comparison sequence	intergranular pores	51.49	54.05	comparison sequence	permeability	0.59	1.23
comparison sequence	feldspar dissolution pores	39.51	29.72	comparison sequence	lithic dissolution pores	5.9	2.7

5.2.3. Calculation of Correlation Coefficient

The correlation coefficient $\delta_i(k)$ represents the correlation coefficient between the reference sequence and the comparison sequence at time k, and its calculation formula is:

$$\delta_i(k) = \frac{\Delta min + \rho \Delta_{max}}{|Y_0(-k) - Y_i(k)| + \rho \Delta_{max}}$$

In the above formula, ρ is the distinguishing coefficient, satisfying $0 < \rho < 1$. The smaller its value, the greater the differences between the correlation coefficients, and the stronger the distinguishing ability. It is generally assigned a value of 0.5. Δmin and Δmax are the minimum and maximum values of the absolute differences among all n comparison sequences at each time point, respectively.

5.2.4. Calculation of Correlation Degree

The correlation coefficient represents the degree of correlation between the comparison data sequence and the reference data sequence at each corresponding time point. Therefore, the coefficients are numerous , making them unsuitable for overall analysis and evaluation. Consequently, it is necessary to calculate the average value of the correlation coefficients at each time point as a measure of the correlation degree between the comparison data sequence and the reference sequence. The correlation degree can be calculated using the following formula:

$$r_i = \frac{1}{m}\sum_{k=1}^{m} \delta_i(k)$$

Table 3. Parameter Correlation of Influencing Factors

influencing factor	Correlation	influencing factor	Correlation
displacement pressure (MPa)	0.861	kaolinite	0.862
median pressure (MPa)	0.849	others	0.810
median radius (μm)	0.666	chlorite	0.703
sorting coefficient	0.932	calcite	0.810
variation coefficient	0.894	ferroan calcite	0.810
maximum mercury saturation (%)	0.991	siliceous material	0.810
mercury ejection efficiency (%)	0.948	total	0.936
intergranular pores	0.995	porosity	0.987
feldspar dissolution pores	0.923	permeability	0.816
lithic dissolution pores	0.871	intercrystalline pores	0.751

Grey correlation analysis of the influencing factors was performed using SPSS software. Parameters with relatively high correlation coefficients were selected for further analysis, and those with correlation coefficients above 0.95 were considered as main controlling factors. Based on the degree of grey correlation, the influencing factors for the three categories of parameters related to development performance were ranked. It can be observed that: 1) The main controlling factors for production within one year of commissioning, in descending order of influence, are intergranular pores, maximum mercury saturation, and porosity; 2) The main controlling factors for the decline rate within one year of commissioning, in descending order of influence, feldspar dissolution pores, injection pore volume multiple, porosity, and intergranular pores.

6. Analysis of Main Controlling Factors for Development

The Chang 8 reservoir in the Longdong area is sourced solely from the southwestern provenance, whereas the Jiyuan area receives sediments from both western and northern provenances. Consequently, the Longdong area exhibits relatively homogeneous petrological characteristics, developing predominantly lithic feldspathic sandstone. In contrast, the Jiyuan area primarily develops lithic feldspathic sandstone, followed by feldspathic lithic sandstone and feldspathic sandstone, with more complex petrological features that increase the difficulty of Chang 8 reservoir development. Both areas share common characteristics of proximal sediment sources, stable and abundant sediment supply, good lateral continuity, and significant thickness.The pore types in the Jiyuan and Longdong areas are generally similar, with both primarily developing intergranular pores and feldspar dissolution pores. However, the Longdong area contains more intergranular pores compared to the Jiyuan area, along with the development of other pore types. Grey correlation analysis has identified intergranular pores as the main controlling factor for productivity, which explains the higher productivity in the Longdong area compared to the Jiyuan area (3.2×10^4 t and 3.0×10^4 t, respectively). High-pressure mercury injection experiments indicate that maximum mercury saturation represents the theoretical maximum porosity of the reservoir. Furthermore, the Chang 8 reservoir predominantly consists of lithologic traps with few structural traps, providing natural spaces for hydrocarbon accumulation and thereby enhancing productivity.

Grey correlation analysis reveals that the main controlling factors affecting the decline rate are final oil displacement efficiency and injection pore volume multiple derived from water flooding experiments, along with intergranular pores and feldspar dissolution pores. Analysis indicates that both final oil displacement efficiency and injection pore volume multiple in the Longdong area are higher than those in the Jiyuan area, resulting in a lower decline rate in the Longdong area. Although the Longdong area has slightly more intergranular pores than the Jiyuan area, the difference is not substantial. This leads to faster initial production rates in the Jiyuan area during early development, followed by rapid productivity decline in later stages, ultimately resulting in a higher decline rate in the Jiyuan area.

7. Conclusion

1.The Longdong area primarily develops lithic feldspathic sandstone, whereas the Jiyuan area, influenced by sediment sources from both the western and northern directions, also develops feldspathic sandstone and feldspathic lithic sandstone. The interstitial material content in the Longdong area is higher than that in the Jiyuan area, with chlorite being abundantly developed. This chlorite content has, to some extent, mitigated the damage of compaction on reservoir physical properties and contributed to the preservation of primary intergranular pores. In contrast, the Jiyuan area exhibits higher kaolinite content in its interstitial materials, leading to the formation of abundant feldspar dissolution pores during later diagenetic stages.

2.The reservoir spaces in the Chang 8 reservoir of both the Longdong and Jiyuan areas are predominantly intergranular pores and feldspar dissolution pores. The Jiyuan area has an average porosity of 10.01% and an average permeability of 0.52×10^{-3} μm^2, classifying it as a super-low permeability reservoir. The Longdong area shows an average porosity of 10.02% and an average permeability of 1.27×10^{-3} μm^2, generally characterized as an ultra-low permeability reservoir. The reservoir pore throats are predominantly small to medium-sized, with abundant fine pore throats, resulting in a relatively complex pore-throat structure.

3.Five factors—provenance, interstitial materials, pore types, pore structure, and final oil displacement efficiency from water flooding experiments—are interconnected and collectively control the development of the Chang 8 reservoir in the study area. Different source directions in various regions have resulted in more complex rock types in the Jiyuan area, with varying interstitial materials leading to different pore types (intergranular pores and feldspar dissolution pores). Mercury injection experiments indicate higher final mercury saturation, suggesting that the Longdong area has larger reservoir space compared to the Jiyuan area. Additionally, since the Chang 8 reservoir is a lithologic reservoir, this contributes to the higher production in the Longdong area relative to the Jiyuan area. Water flooding experiments demonstrate better final oil displacement efficiency in the Jiyuan area, resulting in higher initial production rates during early development stages but insufficient later-stage production, thereby exhibiting a higher decline rate than the Longdong area.

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