Academic Journal of Science and Technology
ISSN: 2771-3032 | Vol. 15, No. 1, 2025

Tectonic Characterization and Sedimentary Microphase Control Mechanism in The Sweet Spot of Chang7 Shale Reservoir in Qingcheng Oilfield

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Abstract: The long 7 shale oil reservoir in Qingcheng Oilfield is one of the important shale oil resources in Ordos Basin, and its sweet spot plays a key role in the formation and distribution of hydrocarbon reservoirs. Through the systematic analysis of the tectonic features and sedimentary microphase of the Qingsheng Oilfield Chang7 Shale Reservoir, this paper discusses the reservoir control mechanism of the sweet spot zone, studies the tectonic background and evolution process of the zone, and reveals the overall tectonic complexity of the zone and the controlling effect of the local small tectonic units on the distribution of hydrocarbons. By analyzing the spatial distribution of sedimentary phase zones and sedimentary microphases, we focus on the influence of different sedimentary phase types on the oil and gas rich areas, especially the key role of waterway sands and turbidite deposits in the dessert zone. Combined with reservoir characteristics and reservoir control factors, this paper analyzes the hydrocarbon enrichment mechanism of the sweet spot zone and predicts its potential in future development. The study shows that the tectonic and sedimentary microphase characteristics of the sweet spot zone of the Qincheng Oilfield Long 7 Shale Reservoir closely affect the distribution and storage of hydrocarbons, and it has a large potential for development. The research in this paper provides theoretical support and practical basis for the exploration and development of the Long 7 shale reservoir.

Keywords: Qingcheng Oilfield, Long 7 Shale Oil, Tectonic Characteristics, Sedimentary Microphase, Reservoir Control Mechanisms.

1. Introduction

With the increasing demand for energy, shale oil, as an important unconventional energy resource, has received widespread attention[1]. As an important oil and gas producing area in China, the Ordos Basin with its long 7 shale reservoir is considered one of the key targets for shale oil development[2]. The Qingcheng oil field is located in the southwestern part of the Ordos Basin, and the long 7 shale oil reservoir has a wide distribution and high resource potential in this area[3]. However, due to the tectonic complexity and the diversity of depositional environments in this reservoir, the distribution and enrichment mechanism of hydrocarbons have not been fully clarified, especially the reservoir control mechanism in the sweet spot area has not been fully studied.

The sweet spot zone of a reservoir usually refers to the area with the best storage conditions and hydrocarbon enrichment, and it plays a crucial role in shale oil development[4]. An in-depth study of the tectonic features and sedimentary microphase distribution in the sweet spot zone is of great significance for accurately predicting the reservoir distribution, improving the development efficiency, and optimizing the oilfield development plan[5]. Most of the past researches focused on the overall characteristics of the Long 7 oil formation and its exploration and evaluation, and lacked systematic research on the tectonic control of the sweet spot area and the relationship between sedimentary microphase and hydrocarbon enrichment[6]. In this paper, we will analyze the tectonic features and sedimentary microphase of the sweet spot zone of the Long 7 shale reservoir in the Qincheng Oilfield, and discuss the control of the depositional environment and tectonic evolution on hydrocarbon enrichment. The study aims to reveal the main factors affecting oil and gas reservoirs in the dessert zone and provide theoretical basis and technical support for the exploration and development of the zone.

2. Tectonic Characterization of the Long 7 Shale Reservoir in the Qincheng Oilfield

Qingcheng Oilfield is located in the southwest of Ordos Basin, which is a typical inland lake basin sedimentary area. The Chang7 shale oil reservoir is mainly distributed in the Triassic Yanchang Formation, with a complex depositional environment, and the tectonic evolution has experienced multiple superposition and deformation[7]. The tectonic evolution of the area is influenced by multiple tectonic movements, which is mainly manifested in the monoclinic tectonics of east-high and west-low, and the local development of small nasal uplift and fracture zones[8]. The regional tectonic pattern is generally stable, but due to the differences in the sedimentary basins, a complex oil and gas reservoir system with obvious local characteristics has been formed.

Qingcheng Oilfield Area 15 is located in the registration area of "Gansu Ordos Basin Xifeng Oilfield Exploitation", with the exploitation license number of 0200000720347, valid from October 2007 to October 2051; "Shaanxi and Gansu Ordos Basin Upper Border A1 Oil and Gas Exploration "Shaan-Gan Ordos Basin A1 Oil and Gas Exploration" registration area, exploitation license No. T10000020230110180012 98 (figure 1):

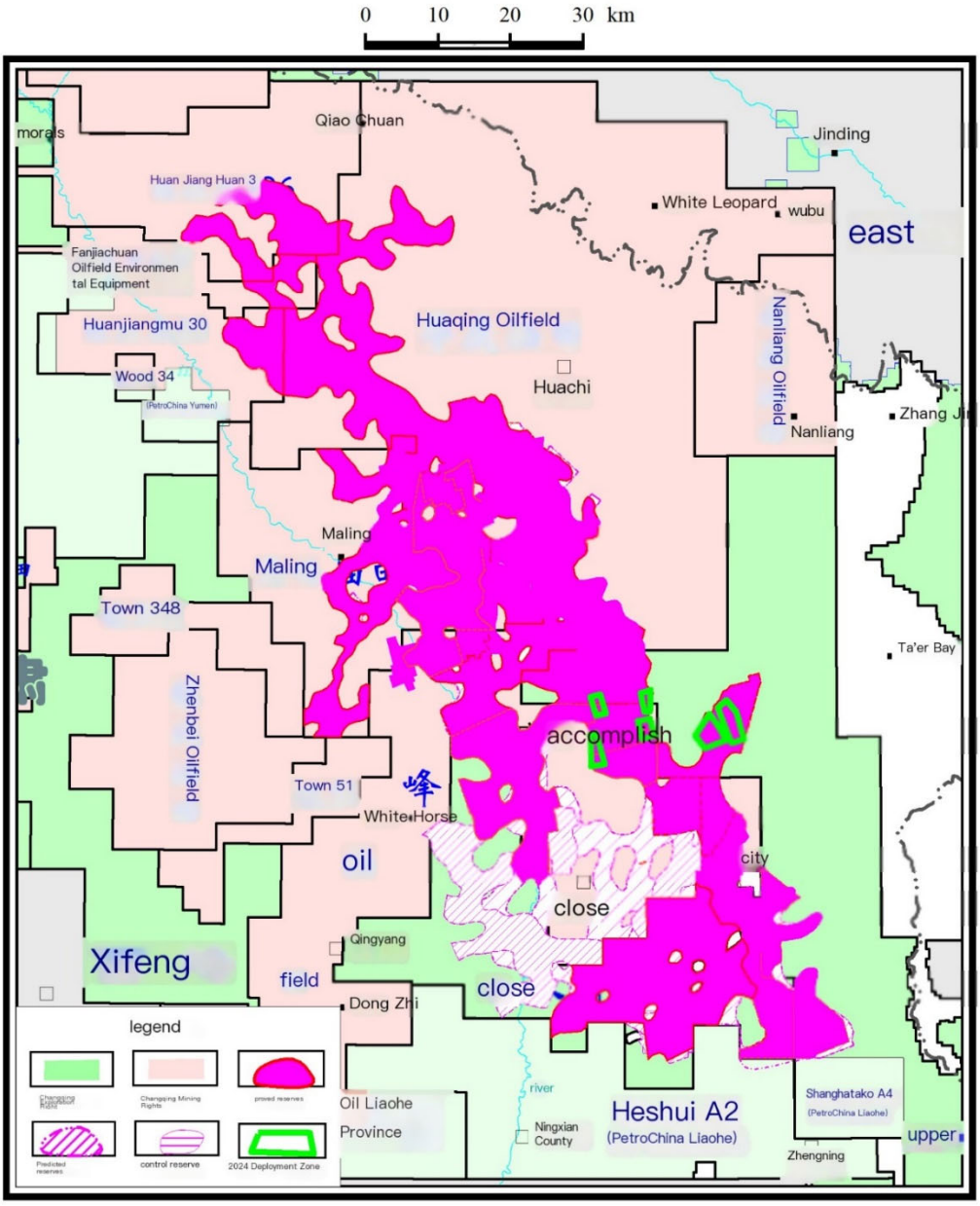

Figure 1. Qingcheng oil field plate 15 area

In the long 7 reservoir of Qingcheng Oilfield, the sweet spot area refers to those areas with the best storage conditions and hydrocarbon enrichment. The tectonics of this zone is relatively simple, mainly showing the tectonic characteristics of west-dipping monoclinic, and the dip angle of the strata is gentle, about 0.5 degrees[9]. Small localized nose-like uplift is developed in the area, and the oil layer shows a trend of gradual decline from east to west. The formation of the dessert zone is closely related to the local tectonic features, especially the small uplift and low-slope area, which becomes the oil and gas rich area. The inheritance of tectonic units is strong, especially under the control of tectonic faults in the upper and lower parts of the oil reservoirs, the oil and gas enrichment is obvious[10].

The tectonic features of the Long 7 shale oil formation play an important role in the distribution of hydrocarbons. Influenced by the tectonics, the Long 7 oil formation exhibits certain stratigraphic segmentation and longitudinal variability on a regional scale. Reservoirs in the localized uplift areas within the formation are better developed and rich in hydrocarbon reserves, while the reservoirs near the fault zones are more non-homogeneous, and the hydrocarbon distribution is greatly affected. The tectonic control effect of the oil reservoir is mainly manifested in the formation of oil and gas trap, the local thickness increase of the oil reservoir, and the improvement of reservoir physical properties, which together promote the enrichment and storage of hydrocarbons.

The dessert area of the Chang7 shale reservoir in the Qincheng Oilfield is controlled by obvious tectonic features. In this area, the distribution of oil layers is closely related to tectonic and geological factors, especially the existence of local uplift zones and fracture zones, which provide good storage conditions for oil and gas. The tectonic stability is combined with the distribution of oil and gas rich areas, and the dessert zone becomes a key area for oil and gas enrichment. By analyzing different tectonic units, it can be found that the dessert zone is mainly affected by changes in the depositional environment, tectonic deformation, and reservoir modification, forming oil and gas reservoirs with high productivity, high oil saturation, and good reservoir properties.

3. Influence of Sedimentary Microphase on Reservoir Control Mechanism in Long7 Shale Reservoirs

Sedimentary microphase has an important influence on the reservoir control mechanism of long7 shale reservoirs, and the differences in the depositional environments lead to the development of different microphases, which in turn affects the enrichment and storage of hydrocarbons. Different sedimentary microphases not only affect the distribution and storage of hydrocarbons, but also determine the physical characteristics of the reservoir, the connectivity of the sand body, and the vertical and lateral variability of the reservoir. Therefore, it is of great significance to study the type and distribution of sedimentary microphases and their control on reservoir properties in order to understand the hydrocarbon enrichment pattern and reservoir distribution in the Long 7 shale reservoir. The next analysis will discuss in detail the spatial spreading of sedimentary phase zones, the relationship between the subdivision of sedimentary microphases and hydrocarbon enrichment zones, and the correlation analysis between sedimentary phases and reservoir characteristics.

A. Spatial spreading of sedimentary phase bands

In the Chang7 shale reservoir of Qincheng Oilfield, the spatial spreading of sedimentary phase zones is of great significance to the distribution and enrichment of hydrocarbons. By analyzing the regional geological background and depositional environment, the sedimentary phase zones of the Chang7 oil reservoir mainly include the delta front, lake phase and gravity flow depositional phase. The spatial distribution of each sedimentary phase zone is influenced by different material sources, tectonic movements and hydrodynamic conditions, and shows certain regularity. According to the field profiles, core observations and logging data, there are strong differences in the horizontal and vertical spreading of the sedimentary phases.

From 2016 to 2017, long horizontal well volume fracturing development test was carried out in Huachi and Heshui zones, 31 horizontal wells were implemented, with well spacing of 600-1,000m, horizontal section length of 1,500-2,700m, average transformation of horizontal wells of 16.7 sections, discharge rate of 9.3m3/min, average volume of in-ground fluids of 18,115m3, and initial average daily oil production of single wells was high (10-20t), Initially, the average daily oil production of a single well is high (10-20t), the oil recovery rate is low (0.65-0.81%), the recovery rate is low (5.1-6.3%), and it is not possible to develop on a large scale with efficiency,showed in Figure 2 :

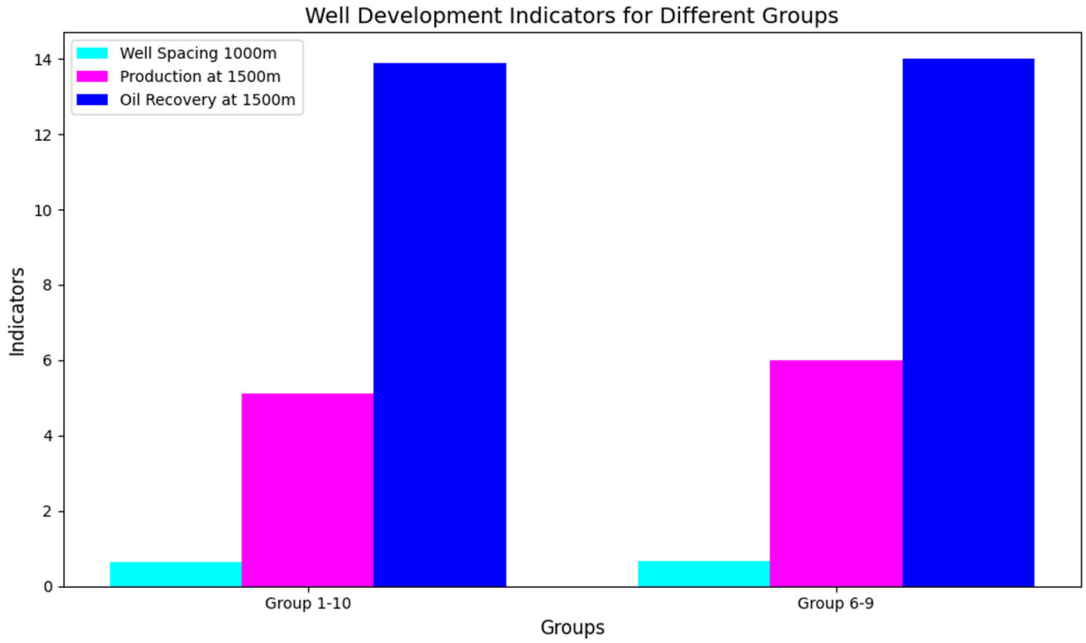

Figure 2. Well Development Indicators for Different Groups

The delta-front sedimentary phase zone of the Long 7 shale reservoir is mainly distributed in the edge area of the lake basin. The sedimentary features in this area mainly include underwater diverging channels, sandy debris flow and turbidite deposition, etc. The distribution of sand bodies is more concentrated and the thickness of sand bodies is larger. The water current power is strong, the grain of sand body is thicker, the deposition rate is faster, and a higher quality reservoir is formed. The sedimentary zone at the front edge of the delta is a favorable area for oil and gas enrichment, especially in the tectonic uplift area, the sediment source is more abundant, and the conditions for oil and gas gathering are superior.

The lake-phase sedimentary phase zone is widely distributed in the central part of the Long 7 shale reservoir, and the sediments are mainly mudstone, gray-black shale and siltstone. The water depth of the lake basin is large, the grain size of the sediments is fine, and the depositional environment is relatively stable. The physical properties of the reservoirs in this zone are poor, and the hydrocarbon storage mainly depends on the richness of organic matter and the development of hydrocarbon source rocks. Although the reservoir quality of the lake-phase sedimentary zone is relatively low, it has become one of the important oil and gas

reservoirs of the Chang7 oil formation due to its wide distribution, especially in the shallow water depth of the lake basin, where the alternation of sandstone layers and mudstone layers forms a more complex reservoir structure.

The distribution of gravity flow depositional phase zone in the Long 7 reservoir is relatively localized, usually developed in the transition zone from semi-deep lake to deep lake phase. Due to the large water depth and weak current power, the sediments are dominated by fine-grained sandstones and mudstones. The reservoirs in this phase zone have strong non-homogeneity, the thickness of the sand body is thin, and the lateral continuity is poor. Nevertheless, the gravity flow depositional zone still has certain potential for hydrocarbon enrichment, especially in the area where the reservoir is close to the hydrocarbon source rock, and the conditions for hydrocarbon storage are relatively good.

B. Subdivision of sedimentary microphases in relation to hydrocarbon rich zones

In the Long 7 shale reservoir of Qincheng Oilfield, the subdivision of sedimentary microphase plays an important role in the hydrocarbon enrichment area. Through core observation and well logging data analysis, the sedimentary microphase of the Long 7 reservoir is mainly divided into the types of waterway microphase, sand dam microphase, lake sedimentary microphase and turbidite sedimentary microphase. The development and spatial distribution of different microphases have significant influence on hydrocarbon enrichment, especially the waterway microphase and turbidite depositional microphase, which are usually the key areas for hydrocarbon enrichment. The detailed delineation of microphases provides a theoretical basis for the distribution and enrichment of hydrocarbons.

The watercourse microphase is usually developed in the sedimentary phase zone of the delta front, which is one of the core areas for hydrocarbon enrichment. The sediments in this microphase are mainly coarse sandstones with high porosity and permeability, which are suitable for hydrocarbon accumulation. The sands in the watercourse microphase usually show better connectivity, especially at the local tectonic uplift and sedimentary ridges, where the hydrocarbon enrichment phenomenon is especially prominent. The contact interface between the watercourse microphase and other microphases often becomes the key part of oil and gas gathering, and becomes the main enrichment zone in the Long 7 reservoir.

The sand dam microphase is mainly distributed in the edge area of the lake sedimentary zone, and its sediments are mainly fine sandstone and siltstone, with relatively poor physical properties of the reservoir. Although the reservoir properties of the sand dam microphase are low, its thickness is large, especially in the local low-slope area, which often forms a more extensive oil and gas rich area. The sand-dam microphase has formed good hydrocarbon storage conditions through the alternate development with the lake-phase sedimentary microphase, which has become one of the hydrocarbon enrichment zones. Hydrocarbons usually gather in the transition zone between the sand dam microphase and the lake microphase, forming a more complex hydrocarbon distribution pattern.

The lake depositional microphase is usually developed in the central part of the Long 7 formation, and the sediments are dominated by mudstone and gray-black shale, with a relatively low degree of hydrocarbon enrichment. Despite the low porosity of lake phase sediments, their wide distribution and good contact with hydrocarbon source rocks still provide certain conditions for hydrocarbon enrichment. Especially in the turning and transition zones of the sedimentary phase zone, the reservoir quality of the lake microphase is better, which becomes an important area for hydrocarbon enrichment. The change of lake microphase is closely related to tectonic factors, and it is a non-negligible hydrocarbon enrichment area in the Long 7 reservoir.

The turbidite depositional microphase usually occurs in the semi-deep lake and deep lake area of the Long 7 oil reservoir, which mainly consists of fine sandstone and siltstone, and has better storage performance. The turbidite depositional microphase usually occurs in the lake basin area with larger water depth, with finer sediment grain size, lower porosity and permeability, but in the vicinity of the hydrocarbon source rock, the enrichment effect of hydrocarbons is more significant. Turbiditic sedimentary microphases often alternate with other sedimentary zones, forming favorable conditions for hydrocarbon aggregation. Especially where the hydrocarbon source rocks are in contact with the turbidite depositional zones, the oil and gas enrichment phenomenon is more obvious.

C. Correlation analysis of sedimentary phases and reservoir characteristics

There is a close relationship between sedimentary phases and reservoir characteristics, and changes in the depositional environment directly affect the physical characteristics of oil and gas reservoirs. The sedimentary phases of the Chang7 oil reservoir mainly include different types of depositional zones, such as delta front, lake phase and gravity flow deposition, and the differences of these depositional phases determine the porosity, permeability and reservoir properties of the reservoir. The sand body in the sedimentary phase zone at the front edge of the delta usually shows higher porosity and better permeability due to its stronger hydrodynamic conditions, which is one of the areas with the best reservoir properties in the Long 7 reservoir. The development of this sedimentary phase provides excellent conditions for hydrocarbon enrichment, especially in the area of watercourse microphase, where the reservoir porosity and permeability are most remarkable.

The lake-phase sedimentary zone usually has low reservoir physical properties, and its reservoirs are dominated by fine-grained mudstones and shales with generally poor porosity and permeability. However, the wide distribution of the lake-phase zone and its excellent contact with hydrocarbon source rocks make this zone still an important area for hydrocarbon enrichment. Especially at the junction of lake phase and other sedimentary phases, such as the contact zone between lake sedimentary microphase and delta front or turbidite sedimentary microphase, it often becomes a favorable place for hydrocarbon accumulation. These alternating depositional zones form hydrocarbon aggregation zones with relatively good reservoir quality due to better reservoir characteristics.

Reservoirs in the gravity-flow depositional phase have poor physical properties and are usually developed in the semi-deep to deep-lake zone, with finer grains and generally lower porosity and permeability. However, the sands in the gravity flow depositional zones are generally more inhomogeneous and thinner. Nevertheless, these sedimentary zones still have some hydrocarbon storage capacity, especially in the areas with good contact with hydrocarbon

source rocks, and the hydrocarbons can be better enriched. Turbidite depositional microphases often coexist with gravity flow depositional phases, and have a certain impact on the physical properties of the reservoir, especially in the upper or lower part of the reservoir, and often form a number of oil and gas aggregation zones with high storage capacity.

The relationship between sedimentary phases and reservoir characteristics is also manifested in the lateral and vertical variability of the reservoir. Due to the differences in the spatial spreading of the sedimentary phase zones, the physical properties of the reservoirs also show significant vertical and horizontal variability. Delta fronts and lake-phase alternation zones usually have better reservoir capacity, while deep lakes and gravity-flow depositional zones have poorer reservoir physical properties. Laterally, the transition zones between different sedimentary phases tend to show strong non-homogeneity, and localized small tectonic deformation, fracture zones and other factors have more significant effects on the reservoir. Therefore, changes in sedimentary phases not only affect the porosity and permeability of the reservoir, but also determine the enrichment and distribution of hydrocarbons, revealing the controlling role of sedimentary phases on reservoir characteristics.

4. Controlled Storage Mechanism and Development Potential of The Dessert Zone

The dessert zone of the Chang7 shale reservoir in the Qingcheng Oilfield is an important area for hydrocarbon enrichment, and its reservoir control mechanism is mainly affected by the combined effects of tectonics, sedimentary microphase and reservoir properties. First of all, the formation of the dessert zone is closely related to the tectonic evolution of the area . Local small-scale uplift, fracture zones and the concentrated distribution of sediment sources provide good oil and gas trap conditions and form highly productive oil layers. Especially in the tectonic lows and local stratigraphic folds of the Long 7 oil layer, the oil and gas enrichment is well controlled. Tectonics plays a crucial role in the accumulation of hydrocarbons, and the dessert zone tends to have stronger hydrocarbon accumulation capacity and higher hydrocarbon reserves.

The distribution of sedimentary microphases is also a key factor influencing the reservoir control mechanism in the dessert zone. The watercourse microphase and sand dam microphase in long7 shale reservoirs usually have better reservoir physical properties, higher porosity and permeability, which become favorable areas for hydrocarbon enrichment. Reservoirs in the sweet spot area are usually developed within these high-quality sedimentary phase zones, and changes in sedimentary phases are very closely related to hydrocarbon enrichment. Under the joint action of sedimentary microphase and tectonics, the sweet spot zone becomes the main area for hydrocarbon accumulation, and the coordination between sedimentary phase and reservoir characteristics plays a key role in the accumulation of hydrocarbons. Based on the capacity prediction parameters, an empirical formula for single-well capacity prediction of horizontal wells was fitted using a multinomial regression method:

$$Q=26.67\times(\varphi*So/\mu)+0.31\times L+0.093\times L\times H \quad (1)$$

Q - cumulative oil production of a single well in the first year (t); φ - porosity (%); μ - surface crude oil viscosity (mPa-S); So - oil saturation (%); L - length of horizontal section I + II type oil layer (m); H - thickness of oil layer (m).

The degree of correlation between production capacity and each factor obtained by the gray correlation analysis method was used to analyze that among the geological factors affecting the cumulative oil production in the first year, φ*So, brittleness index, and φ/μ were the main influencing factorsZ:

$$\begin{gathered}\text{Oil content: } \varphi\times So \\ \text{Fluid fluidity: } k/\mu\rightarrow\varphi/\mu \\ \text{Reservoir quality factor (RQI): } \sqrt{k}/\varphi\end{gathered} \quad (2)$$

In addition to the role of tectonic and sedimentary phases, the physical and lithologic characteristics of reservoirs are also important factors affecting the reservoir control mechanism in the dessert zone. Reservoirs in the sweet spot area usually have high porosity and good permeability, which provide ideal conditions for the storage and flow of hydrocarbons. Especially in the area where the development of sand bodies is more concentrated and the physical properties are more excellent, the degree of oil and gas enrichment is higher. Good lithological combinations in the reservoir, such as the alternating development of sandstone and mudstone, also provide an effective barrier and storage space for hydrocarbon enrichment. In addition, the high quality and maturity of the hydrocarbon source rocks also provide a guarantee for oil and gas enrichment in the dessert area.

From the perspective of development potential, the sweet spot area has greater potential in the development of long7 shale reservoirs. First of all, the sweet spot zone is relatively rich in oil and gas resources and has better development conditions. With the continuous progress of horizontal well technology and fracturing technology, the development potential of the dessert zone will be further released. According to the existing geological evaluation and engineering test data, the development efficiency and economic benefits of the sweet spot zone are good, and it is expected to become an important contributor to oilfield production in the future development. By optimizing the development plan and improving the recovery rate, the dessert zone is expected to become the core development area of the Long 7 shale reservoir and provide strong support for the sustainable development of the oilfield.

5. Conclusion

The dessert zone of the Chang7 shale reservoir in the Qincheng Oilfield has important hydrocarbon enrichment and storage potential, and its reservoir control mechanism has been revealed through a comprehensive analysis of the tectonic features, sedimentary microphase, and reservoir properties of the zone. The study shows that the hydrocarbon enrichment in the dessert zone is mainly influenced by tectonic factors, spatial distribution of sedimentary phase zones and reservoir properties. The good combination of small uplifts, fracture zones and sedimentary microphases formed by tectonic evolution makes the sweet spot area have ideal conditions for oil and gas reservoirs. In addition, the reservoirs in the dessert zone usually show better porosity and permeability, especially in the areas where the watercourse microphase and sand dam microphase are developed, the physical properties of the reservoirs are better, which

becomes a key zone for hydrocarbon enrichment.

The variations in sedimentary microphases are closely integrated with tectonic features, especially in the delta front and the lake-phase junction zone, where the variability of the depositional environment has led to the concentrated distribution of hydrocarbons. Further analysis reveals that the transition zones of sedimentary phase zones, especially the junction of turbidite and watercourse sedimentary zones, tend to form hydrocarbon enrichment zones. The reservoir-control mechanism of the dessert zone is not only influenced by the sedimentary phase zone, but also strengthened by the tectonic control effect, and the joint action of sedimentary phase and tectonics makes this zone become the main hydrocarbon enrichment area.

In terms of development potential, the sweet spot area has significant development prospects. With the continuous progress of horizontal well technology and fracturing technology , the development potential of the sweet spot area will be further released. Existing exploration and development data show that the area is rich in oil and gas resources and has been well developed, and is expected to become a major source of production in the future development of the oilfield. By further optimizing the development plan and enhancing the recovery rate, the dessert area will provide strong support for the sustained production of the Long 7 Shale Reservoir. The tectonic features, sedimentary microphase and reservoir characteristics of the sweet spot zone of the Long 7 shale reservoir in the Qincheng Oilfield work together to determine its unique reservoir control mechanism and development potential. Future studies should continue to explore in depth the development technology and resource utilization strategy of this zone in order to achieve more efficient resource extraction and economic benefits.

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