ISSN: 2688-8645

Study on "Four-Property Relationship" and Effective Thickness Lower Limit of Chang4+5 Reservoir in Zhenbei Area

Bolin Fu *, Le Qu, Yang Shen

School of College of Earth Science and Engineering, Xi'an Shiyou University, Xi'an Shaanxi, 710000, China

* Corresponding author: Bolin Fu

Abstract

Zhenbei Area is located on the southwestern margin of the Ordos Basin, north of Zhenyuan County. The Yanchang Formation is a key horizon for oil and gas exploration and development in this region. Although certain exploration achievements have been made in Chang 8, Chang 7 and Chang 3 members of the Yanchang Formation in Zhenbei Area, the Chang4+5 member has multiple oil-producing wells and great exploration potential. Controlled by different sediment sources, the Chang4+5 reservoir in Zhenbei Area is lithologically different from that in adjacent eastern blocks, and can be subdivided into Chang4+5$_2$ and Chang4+5$_1$ sub-members vertically. As a typical low-permeability reservoir with complex oil-water distribution, low resistivity and low oil saturation, it is difficult to identify oil and water layers by conventional methods. Based on core data, grain size analysis, physical property parameters, logging and production performance data, this study systematically analyzed the four-property relationship (lithology, physical property, electrical property and oil-bearing property) of the Chang4+5 reservoir in Zhenbei Area, established logging interpretation models, and clarified the lower limits of physical property, oil-bearing property, electrical property and effective thickness. The results show that the Chang4+5 reservoir is dominated by fine sandstone and extra-fine sandstone, with low porosity and extra-low permeability; obvious electrical differences exist between eastern and western parts of the study area; the lower limits of physical property are porosity >9% and permeability >0.1 mD, and the lower limit of effective thickness is 0.4 m. This study provides a reliable basis for reservoir evaluation, fluid identification and reserve calculation of the Chang4+5 reservoir in Zhenbei Area.

Keywords

Zhenbei Area; Chang4+5 Reservoir; Four-Property Relationship; Effective Thickness Lower Limit; Logging Interpretation.

1. Introduction

Zhenbei Area is located on the southwestern margin of the Ordos Basin, north of Zhenyuan. The Yanchang Formation is an important horizon for oil and gas exploration and development in this region [1]. At present, certain exploration and development achievements have been made in Chang 8, Chang 7, Chang 3 and other horizons of the Yanchang Formation in Zhenbei Area, and some horizons are highly developed [2-4]. Meanwhile, multiple oil-producing wells have been discovered in Chang4+5 of this area, indicating certain exploration and development potential. However, the Chang4+5 sedimentary period in Zhenbei Area and the Chang4+5 in its adjacent eastern blocks are controlled by different sediment sources, resulting in differences in lithologic and mineral components. Vertically, Chang4+5 can be subdivided into two sub-layers: Chang4+5$_2$ and Chang4+5$_1$ according to sedimentary cycles. The Yanchang Formation reservoir is a low-permeability reservoir with complex hydrocarbon migration and accumulation rules, complex oil-water relationships, widely developed low-saturation reservoirs and locally developed sweet spots. The overall low resistivity of the reservoir makes it difficult to identify oil and water layers [5], requiring a combination of multiple methods for oil layer research.

2. Study on Reservoir "Four-Property Relationship"

The study on reservoir four-property relationship refers to the research on the lithology, physical property, electrical property, oil-bearing property of reservoirs and their interrelationships, which is the basis for identifying fluid properties in reservoirs and calculating reserve parameters [6]. In this study, core, grain size, physical property parameters, mud logging, well logging and production performance data are comprehensively used to study the four-property relationship of the Chang4+5 reservoir in Zhenbei Area, and to establish the identification standard for Chang4+5 oil layers.

2.1. Lithology Characteristics

Rock grain size analysis was carried out on the basis of previously collected regional drilling rock data. According to the clastic rock particle size classification standard, the results show that the Chang4+5 reservoir in the study area is dominated by fine sandstone and extra-fine sandstone, accounting for 64% and 22% of the total samples respectively, followed by medium sandstone (12%) and siltstone (<2%). Core observation and thin section identification data show that the reservoir sandstone types of Chang4+5 in the study area are mainly lithic arkose and feldspathic lithic sandstone, followed by lithic quartz sandstone, with medium–good sorting and mainly subangular rounding, with few subangular–subrounded grains.

According to rock thin section identification and analysis, the interstitial materials in the study area mainly include clay mineral cements (illite, chlorite), carbonate cements (calcite, ferrocalcite, ankerite) and siliceous cements (authigenic quartz, etc.). The average content of interstitial materials in the eastern part of the study area is 12.02%, and the clay components are mainly illite and kaolinite. Other cement components include siliceous, ankerite and ferrocalcite, with contents equivalent to those of clay cements. The content of interstitial materials in the western part is relatively low, with an average total content of 8.6%, and the composition of interstitial materials is basically the same as that in the eastern part.

2.2. Physical Property Characteristics

According to conventional analysis and test data, the main reservoir spaces of Chang4+5 in the study area are various pores. The pore types are mainly intergranular pores and dissolved pores, including feldspar dissolved pores and lithic dissolved pores, with local intergranular dissolved pores, a small amount of intercrystalline pores and very few microfractures.

The porosity of the study area is mainly distributed in 8%–15% with an average of 11.6%; the permeability is mainly distributed in 0.1–1.0 mD with an average of 0.7 mD. The reservoir is generally a low-porosity and extra-low permeability reservoir.

2.3. Electrical Property Characteristics

The Chang4+5 reservoir sand bodies in the study area are stably developed with small thickness variation, generally 3–10 m. However, the reservoir sand bodies have spatial heterogeneity. If the whole reservoir is studied as a whole, the controlling factors of reservoir characteristics in different regions will be different, causing research difficulties. Therefore, before electrical property research, the study area is divided into eastern and western parts according to sedimentary characteristics and light mineral distribution.

ISSN: 2688-8645

The western part of the study area has good physical properties. Based on oil test data of 31 wells and logging data, 66 sub-layer data points were extracted. The electrical properties of oil layers are characterized by low gamma ray (60–100 API), medium–low acoustic transit time (216–247 μs/m), medium–high density (2.37–2.47 g/cm^3) and medium–high resistivity (5–73 Ω·m), with resistivity mainly distributed in 8–20 Ω·m. The eastern part is relatively tight with high formation water salinity (70–130 g/L). The electrical parameters of oil layers vary greatly, mostly low-resistivity oil layers, with oil and water produced simultaneously in oil tests. Based on oil test data of 25 exploration and evaluation wells and logging data of 36 wells with oil shows, 139 sub-layer data points were extracted. The electrical properties are low gamma ray (45–80 API), medium–low acoustic transit time (206–237 μs/m), medium–high density (2.37–2.58 g/cm^3) and medium–low resistivity (4–40 Ω·m).

2.4. Relationship between Physical Property and Oil-Bearing Property

Physical property is a key factor controlling the oil-bearing property of reservoirs. The oil-bearing property of reservoirs will be significantly improved only when both porosity and permeability reach a certain level (Figure 1). Macroscopically, it is manifested as hydrocarbon shows in rocks, reflecting the control of physical property on oil-bearing property to a certain extent [7].

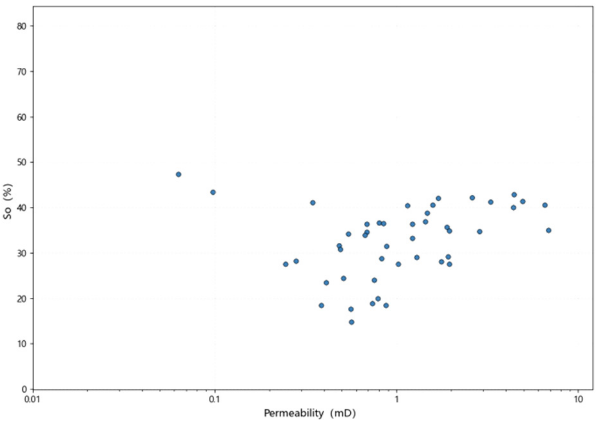


Figure 1. Crossplot of Permeability and Oil Saturation

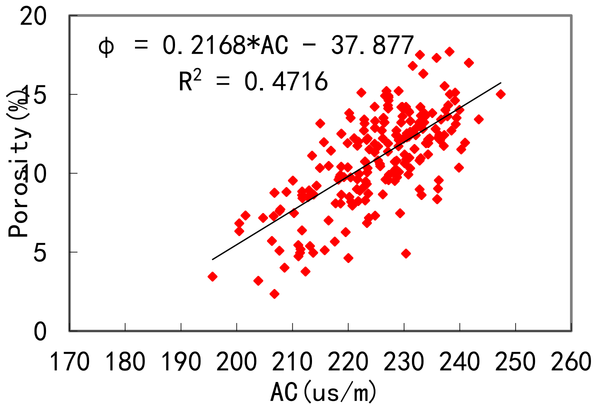
2.5. Establishment of Logging Interpretation Model

(1) Shale Content Model

Gamma ray is an effective method for dividing mudstone and calculating shale content. However, affected by high radioactivity anomalies, gamma ray alone is difficult to accurately reflect shale content in some reservoirs. Studies have shown that high gamma ray values are widely developed in the Chang4+5 reservoir in Zhenbei Area. Therefore, on the basis of the original gamma ray division method, this study adopts the neutron-density logging method to calculate shale content, and the calculation formula is as follows [8]:$V_{sh}=(\Phi_N-\Phi_D)/(\Phi N_{sh}-\Phi D_{sh})$Where: V_{sh} is shale content; Φ_D and Φ_{Dsh} are density apparent porosity of argillaceous sandstone and mudstone respectively; Φ_N and ΦN_{sh} are neutron apparent porosity of argillaceous sandstone and mudstone respectively.

(2) Porosity Interpretation Model

A crossplot of acoustic transit time and core analysis porosity of the Chang4+5 reservoir was established using data from 25 standard wells. About 75% of the data are distributed near the fitting line (Figure 2), indicating that it is feasible to predict reservoir porosity in this area using AC or DEN logging data.



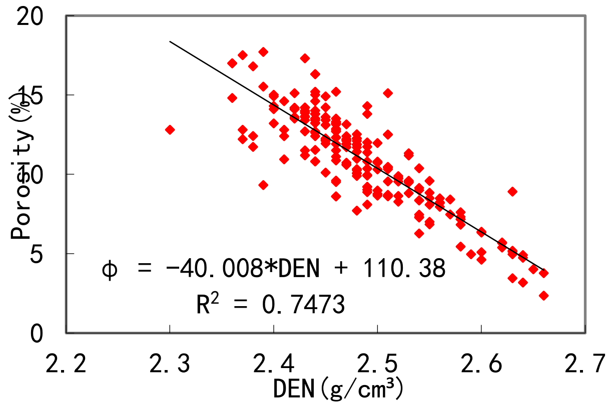


Figure 2. Crossplots of Porosity vs. AC (Left) and Porosity vs. DEN (Right) of Chang4+5 Reservoir in the Study Area

(3) Permeability Interpretation Model

Extra-low permeability reservoirs have low logging signal-to-noise ratio and complex diagenesis, with little information from reservoir pores collected during logging. It is usually difficult to establish a permeability interpretation model with strong adaptability [8]. The relationship between analyzed porosity and analyzed permeability of the Chang4+5 reservoir in 15 standard wells in Zhenbei Area shows that there is a certain correlation between analyzed permeability and analyzed porosity. Some data deviate from the trend, which may be affected by sedimentation and diagenetic evolution, with local high-permeability areas or tight physical property areas (Figure 3).

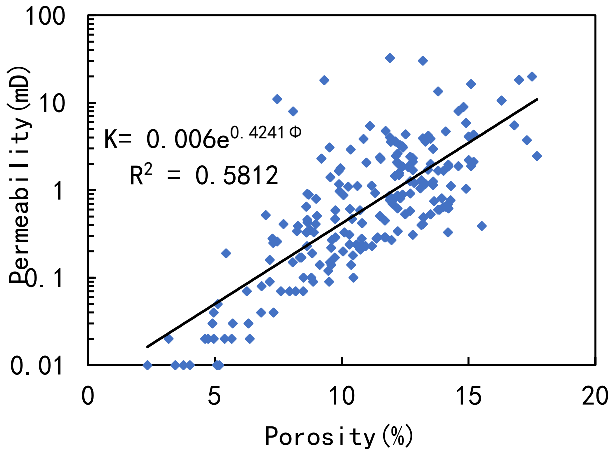


Figure 3. Crossplot of Porosity vs. Permeability of Chang4+5 Reservoir in the Study Area

2.6. Relationship between Electrical Property and Oil-Bearing Property

The conventional crossplot method of RT, AC and DEN was used to identify oil and water layers of Chang4+5 in the study area, but the application effect was not ideal. Therefore, on the basis of the crossplot method, the apparent resistivity increase rate method and array induction gradient factor method were comprehensively used to study the oil-water relationship in the study area.

Resistivity logging is an important means to judge oil-bearing property and identify oil and water layers. Generally, oil layers have higher resistivity. However, under the background of low resistivity in the study area, this trend is not obvious. Low resistivity of oil layers is generally related to high formation water salinity, high irreducible water saturation and mineral conductive mechanism [9], so it is difficult to identify the relationship between

ISSN: 2688-8645

electrical property and oil-bearing property by conventional methods. Therefore, apparent resistivity increase rate (RI) is used to replace electrical property to identify the relationship with oil-bearing property. RI eliminates the influence of lithology and physical property changes on resistivity and highlights oil-bearing property. Resistivity increase rate $RI=R_t/R_o$, where R_t is formation resistivity and R_o is apparent water layer resistivity. Formation water resistivity (Rw) is determined by formation water analysis data, and then apparent water layer resistivity R_o is calculated by variable m index method: $R_o=Rw/\Phi^m$, where $m=2.36\Phi^{0.1134}$. The larger the RI value, the better the oil-bearing property(Figure 4).

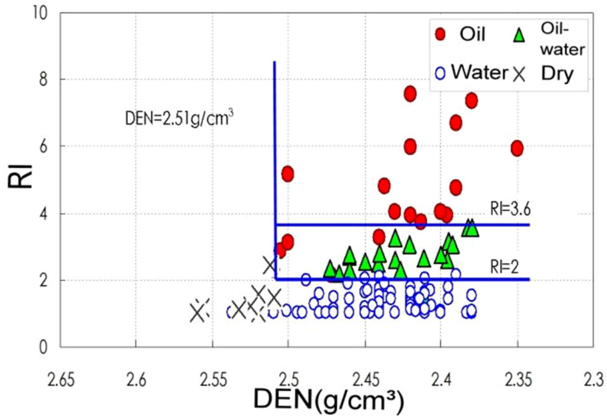


Figure 4. Crossplot of Resistivity Increase Rate vs. Density in the Study Area

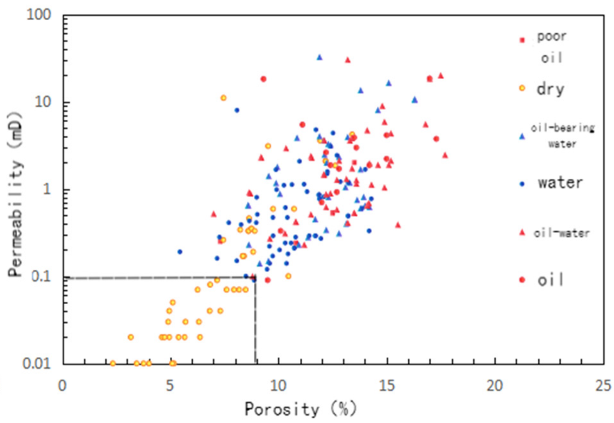


Figure 5. Plot for Physical Property Lower Limit in the Study Area

For the array induction gradient factor Δλ method, the operation is as follows: Δλ is calculated by array induction logging, where Δλ=(AT90-ATi)/AT90. If all gradient factors are positive, it is interpreted as an oil layer; if there are positive and negative gradient factors, it is interpreted as an oil-water layer; if all gradients are negative, it is interpreted as a water layer. The results show that 6 layers were identified by the array induction gradient factor method, 4 layers were consistent, and the re-judgment coincidence rate was 66.7%(Table 1).

Table 1. Statistical Table of Coincidence Rate of Array Induction Gradient Factor Method

Well	Sub-layer	Oil (t/d)	Water(m^3/d)	Interpretation conclusion	ΔAT1	ΔAT2	ΔAT3	ΔAT4	Result
l161	Chang4+5_2	0.01	20.5	Water layer	-0.21	-0.12	-0.02	-0.01	Consistent
z320	Chang4+5_2	7.82	0	Oil layer	0.47	0.28	0.21	0.07	Consistent
z371	Chang4+5_2	6.8	0	Oil layer	-0.07	-0.03	0.02	0.02	Inconsistent
z128	Chang4+5_2	1.36	18	Oil-water layer	0.48	0.19	0.10	0.06	Inconsistent
z111	Chang4+5_1	0	16.2	Water layer	-0.38	-0.19	-0.05	-0.02	Consistent
z96	Chang4+5_2	0	22.7	Water layer	-1.20	-0.64	-0.26	-0.04	Consistent

3. Study on Lower Limit of Effective Thickness

3.1. Lower Limit of Reservoir Physical Property

The low permeability of low-permeability reservoirs is usually caused by multiple factors. Conventional methods for determining the lower limit of oil layer physical property can't give an accurate boundary at once and only serve as a general reference. Based on the method of determining the lower limit of physical property from oil test data, the physical property lower limit of most dry layers in the study area is porosity <9% and permeability <0.1 mD (Figure 5).

3.2. Lower Limit of Reservoir Oil-Bearing Property

Statistical analysis of oil test wells in Zhenbei Area shows that the lithology of Chang4+5 oil layers is generally fine sandstone, and the oil-bearing grades are oil stain and oil patch. Therefore, the lower limit of oil-bearing property is determined as oil stain grade.

3.3. Lower Limit of Reservoir Electrical Property

Under the overall framework of zonal research, combined with crossplot method (Figure 5, Figure 6), resistivity increase rate, array induction gradient factor method and formation water salinity in each region, the lower limit standard of oil layer electrical property is finally obtained (Table 2).

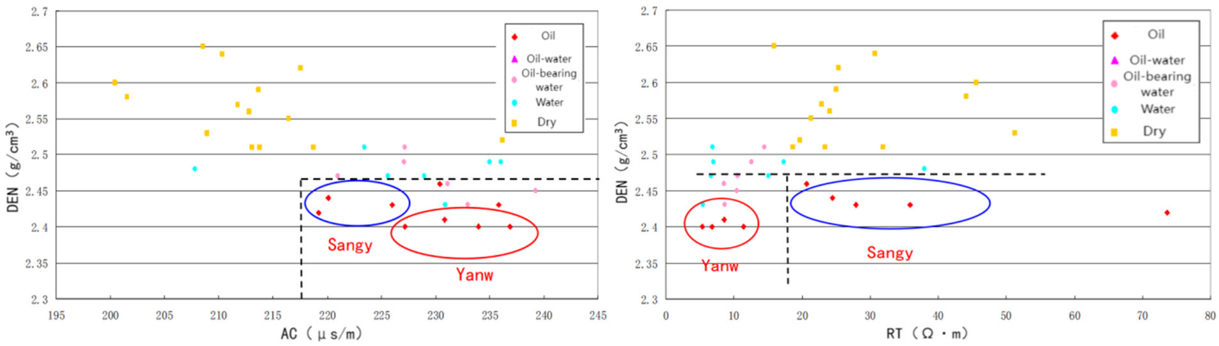


Figure 6. Crossplots of Density vs. Acoustic Transit Time (Left) and Density vs. Resistivity (Right) of Chang4+5 in Western Study Area

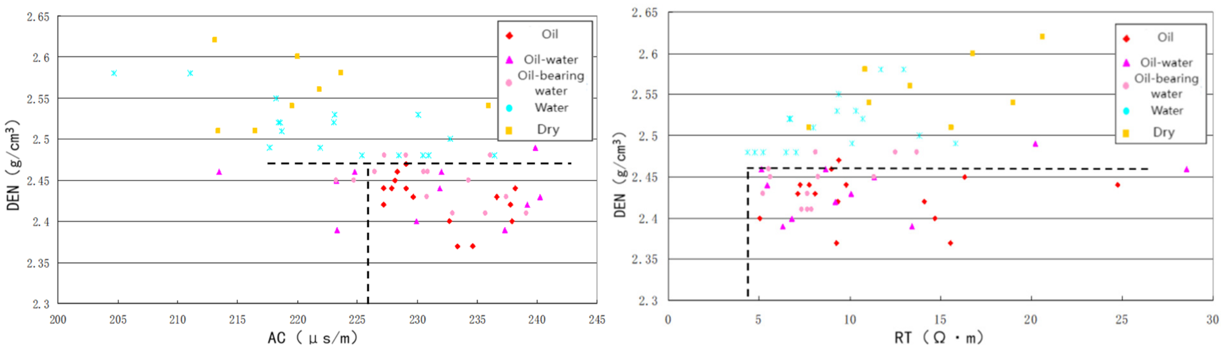


Figure 7. Crossplots of Density vs. Acoustic Transit Time (Left) and Density vs. Resistivity (Right) of Chang4+5 in Eastern Study Area

Table 2. Electrical Parameters of Chang4+5 Oil Layers in the Study Area

Region	Sub-layer	RT (Ω·m)	AC (μs/m)	DEN (g/cm^3)	Total Mineralization (g/L)
West (Sangy)	Chang4+5_1	20	219	2.4-2.46	20-40
West (Yanw)		5-15	227-242	2.4-2.44	75-105
West	Chang4+5_2	12-25	216	2.37-2.47	50-80
East	Chang4+5_1	5	227	2.35-2.46	70-130
	Chang4+5_2	10	221-240	2.40-2.46	50-140

3.4. Determination of Lower Limit of Effective Thickness

Through the comprehensive study on the lower limit standards of physical and electrical properties of the Chang4+5 reservoir in Zhenbei Area, the lower limit standard of effective thickness of the Chang4+5 reservoir in Zhenbei Area is finally obtained (Table 3). Referring to the resolution of existing logging data, the starting thickness of effective thickness is 0.4 m, and the starting deduction thickness of interbeds is 0.2 m [8].

Table 3. Electrical Parameters of Chang4+5 Oil Layers in the Study Area

Interpretation conclusion	Grain size	Shale content (%)	Porosity (%)	Permeability (mD)	Core oil-bearing grade	RT(Ω·m)	AC(μs/m)
Oil layer, Oil-water layer	Fine sandstone	<34	>9	>0.1	Oil stain	>5	>216

4. Conclusion

The Chang4+5 reservoir in Zhenbei Area is dominated by fine sandstone and extra-fine sandstone, with lithic arkose and feldspathic lithic sandstone as the main rock types. It is a low-porosity (average 11.6%) and extra-low permeability (average 0.7 mD) reservoir, with intergranular pores and dissolved pores as the main reservoir spaces.

Obvious zonal differences exist in the electrical properties of the Chang4+5 reservoir: the western part has medium–high resistivity and good physical properties, while the eastern part is tight with low resistivity and high formation water salinity. The shale content, porosity and permeability interpretation models established in this study are suitable for logging evaluation of this reservoir.

The apparent resistivity increase rate method and array induction gradient factor method effectively improve the identification accuracy of oil and water layers in low-resistivity reservoirs, solving the problem of difficult fluid identification in the study area.

The lower limit standards of the Chang4+5 reservoir in Zhenbei Area are clarified: porosity >9%, permeability >0.1 mD, oil-bearing grade > oil stain, RT >5 Ω·m, AC > 216 μs/m. These standards offer important technical support for reservoir evaluation, oil-water layer identification, reserve calculation, and subsequent exploration and development of the reservoir.

References

[1] Yang Quanmin, Yang Lansuo, Li Bo. Sequence stratigraphic division and hydrocarbon-bearing characteristics of Yanchang Formation in Zhenbei Area[J]. Journal of Shaanxi Geology, 2008(01):46-52.

[2] Lü Chengfu, Fu Suying, Li Xiaofeng, et al. Diagenetic facies and high-quality reservoir distribution of Chang 8 oil-bearing formation in Zhenbei Area, Ordos Basin[J]. Journal of Oil and Gas Technology, 2011, 33(07):1-6+6.

[3] Guo Xuanhao, Tan Qianqian, Zhao Junhui, et al. Differential effects of diagenesis on microstructure of tight sandstone reservoirs: A case study of Chang 7 member in Jiyuan and Zhenbei areas, Ordos Basin[J]. Natural Gas Geoscience, 2021, 32(06):826-835.

[4] Zhang Pan. Reservoir evaluation and prediction of Chang 3 member in Zhenbei Area[D]. Xi'an Shiyou University, 2023.

[5] Wang Xuejun, Wang Zhixin, Chen Jie, et al. Petroleum migration and accumulation mechanism of Yanchang Formation in Zhenbei Oilfield, Ordos Basin[J]. Petroleum Exploration and Development, 2011, 38(03):299-306.

[6] Li Jie, Ning Bo, Ma Yukai, et al. Study on four-property relationship of Chang 6 reservoir in Panlong Area, Ordos Basin[J]. Energy and Environmental Protection, 2024, 46(03):115-121+129.

[7] Wang Runhao, Liu Yu, Wang Hongtao, et al. Application of reservoir four-property relationship study in Xinzhuang Oilfield[J]. Natural Gas Exploration and Development, 2006(03):37-39+71-72.

[8] Liu Xi, Li Wenhou, Han Wei. Study on four-property relationship and effective thickness lower limit of Chang4+5 reservoir in Zhenbei Area[J]. Northwestern Geology, 2010, 43(01):124-129.

[9] Zheng Xiaolei. Identification of low-resistivity oil layers and favorable area prediction of Chang 6 reservoir in Yanchang Formation, Tiebiancheng Area[D]. Xi’an Shiyou University, 2024.