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Main Controlling Factors of Shale Oil Enrichment in Yanchang Formation of Yan'an Exploration Area

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Abstract

In order to reveal the enrichment characteristics of shale oil in the southeastern Ordos Basin, the shale samples in Yan'an exploration area were taken as the research object, combined with drilling and logging data, geochemical tests such as organic carbon, rock pyrolysis and vitrinite reflectance were carried out, and the shale gas enrichment and main controlling factors of Yanchang Formation in the study area were discussed in detail. The results show that: 1) The organic carbon (TOC) content of the Chang 7 member of the Yanchang Formation is high, the average TOC content is 4.77%, mainly type I and type II kerogen, the maturity of organic matter is low, and the vitrinite reflectance Ro of shale is mainly 0.8% - 1.05%, generating crude oil associated gas and pyrolysis gas. 2) The organic carbon content, pyrolysis parameters free hydrocarbon (S1) and pyrolysis hydrocarbon (S2) are positively correlated with shale oil content, and vitrinite reflectance Ro is positively correlated with shale oil content, indicating that organic matter abundance and thermal evolution maturity directly control shale oil content. 3) There is a positive correlation between lithology, reservoir and oil content. The development degree of shale physical properties has a controlling effect on the oil content of shale. It is concluded that organic matter abundance and maturity are the basic control factors of shale gas occurrence in Yanchang Formation, followed by physical properties.

Subject Areas

Geoscience, Unconventional Oil and Gas

Keywords

Shale Oil, Organic Carbon, Maturity, Physical Properties

1. Introduction

The exploration and development of shale oil and gas began in the Bakken Formation of the Williston Basin in the United States in the 1950s. With the improvement of geological theory and the progress of mining technology, it has entered a stage of rapid global development [1]. A large amount of shale oil is found in the organic-rich fractured shale of the Upper Jurassic Bazhenov Formation in the West Siberian Basin of Russia. The single well oil production can reach 50 - 1700 m^3/d [2]. A major breakthrough has been made in the exploration of shale oil in the Upper Jurassic Vaca Muerta Formation in the Neuquen Basin, Argentina, with an estimated recoverable reserves of 25.758×10^8 m^3 [3].

The US shale oil and gas revolution was relatively successful, with US shale oil production of 3.85×10^8 t in 2019. It accounts for 65.2% of its total crude oil production [4], breaking the world oil pattern with the Middle East and Russia as the main oil producing areas, and providing an important guarantee for the energy security of the United States. At present, China's external dependence on crude oil has reached 73.5%. As a strategic replacement resource in China's oil and gas field, shale oil is of great significance to alleviate the external dependence of oil and gas and ensure national energy security [5] [6] [7] [8].

China's shale oil exploration started late, continental shale has fast phase transition, complex structure, low formation energy, strong reservoir heterogeneity, heavy oil, high viscosity, poor fluidity, horizontal well fracturing effect is not obvious, and economic development is difficult. It is urgent to clarify the key scientific problems restricting continental shale oil exploration and point out the direction for further research [9]-[13].

Therefore, this paper systematically analyzes the basic geological characteristics of Chang 7 shale in Yanchang Formation in Xiasiwan exploration area of Ordos Basin, clarifies the formation conditions and geological factors of shale oil in Yanchang Formation in the study area, and focuses on the analysis of organic matter abundance, thermal evolution maturity, physical properties and lithofacies on the basis of measured data. The key factors affecting the oil content of Yanchang Formation shale are summarized, and the controlling factors of shale oil enrichment are summarized, which provides guidance for finding favorable exploration targets of shale oil.

2. Geological Background

The total area of the Ordos Basin is about 33.25×10^4 km^2. Because of the rich oil and gas resources in the basin, it has become the second largest oil-bearing sedimentary basin in China [14]. The Yanchang Formation is the main oil-bearing series in the basin. The Xiasiwan exploration area is located in the eastern part of the central and southern part of the Ordos Basin (**Figure 1**), located in Ganquan County, Yan'an City, Shaanxi Province, the study area is about 1.4×10^3 km^2.

The sedimentary facies of Yanchang Formation in Triassic is lacustrine facies as a whole, and some areas are delta facies. There are a large areas of dark mudstone

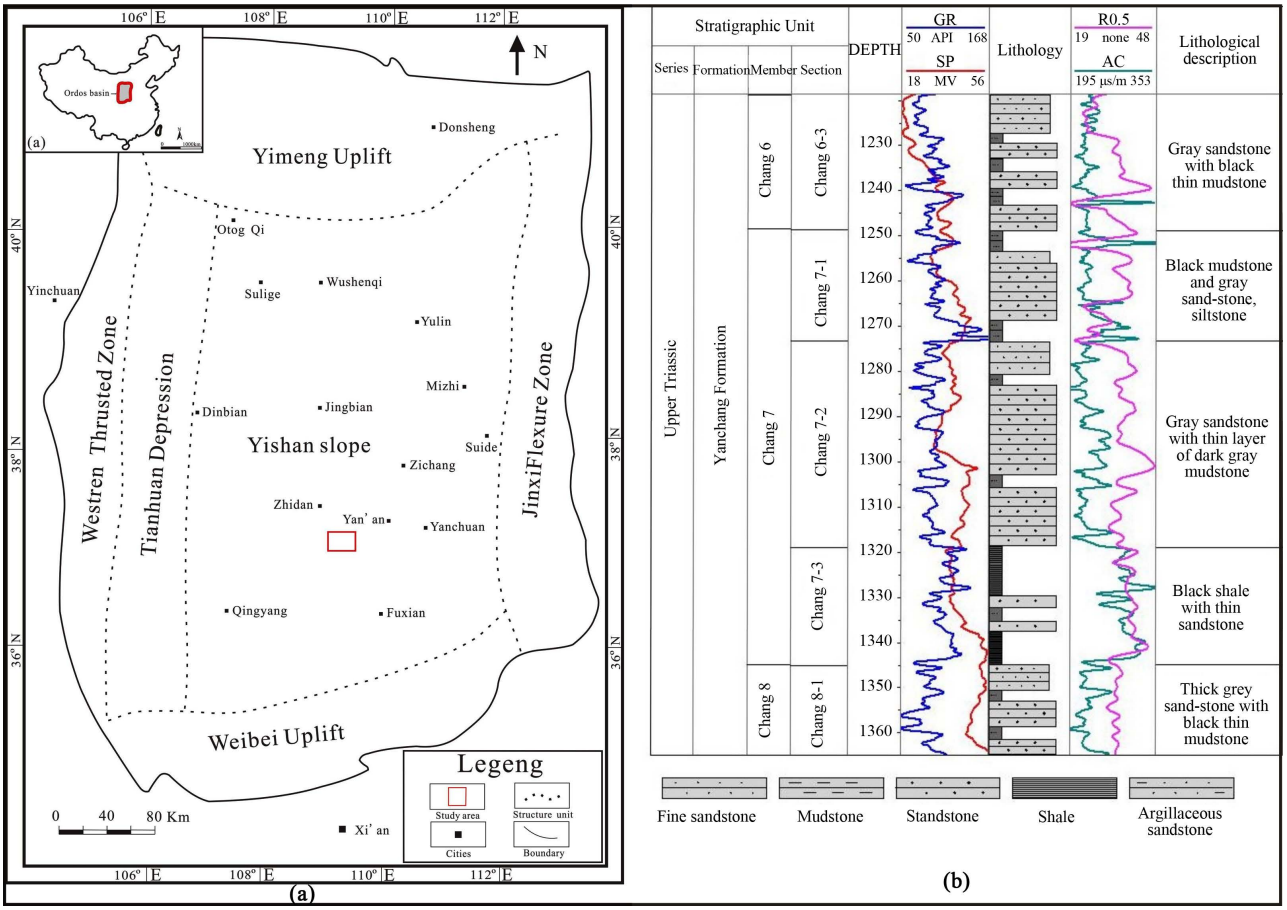

Figure 1. The location and stratigraphic column of the study area.

with high organic matter. The thickness of Yanchang Formation in Xiasiwan exploration area is between 750 - 1422 m, with an average thickness of 1138 m.

The lake basin of the Chang 7 member sinks sharply, which is the largest lake advance period of the Yanchang Formation. The distribution is stable on the plane. The sedimentary facies are mainly semi-deep lake-deep lake, and the lithology is black-black dark shale, which is the main set of source rocks in the basin.

3. Enrichment and Main Controlling Factors

Combined with the practical experience of shale oil exploration in other basins at home and abroad, this study observed the field profile and a large number of drilling core profiles, and through a large number of experimental test data, it is considered that the main controlling factors of shale oil accumulation in the Yanchang Formation in the study area are nothing more than the two main controlling factors of "source" and "reservoir", which are specifically refined into key controlling factors: organic matter abundance, organic matter maturity, lithology, physical properties and fracture development degree.

3.1. Organic Matter Abundance

The shale of the Yanchang Formation is mainly developed. The "Zhangjiatan"

shale in the middle and lower part of Chang 7 (Chang 7_3, Chang 7_2) is a condensed layer formed during the maximum flooding surface of the lake basin. The lithology is mainly black oil shale, dark gray mudstone, gray mudstone and silty mudstone. A set of fine-grained sediments, its hydrocarbon-generating parent material kerogen is mainly type I and type II, mainly composed of sapropel components formed by low-level planktonic aquatic organisms, accompanied by a small amount of humus components formed by higher terrestrial plants around the lake basin, with high organic matter abundance, is the main material basis for generating oil and gas.

In the Chang 7 shale, the samples with organic carbon content less than 1% are excluded. Among the 615 measured samples, the organic carbon of Chang 7 is distributed in the range of 1% to more than 10%, the main distribution range is between 3% - 6%, the main peak is 4% - 5%, and the average content is 4.77%. High organic carbon content is the basic element of oil and gas generation (Figure 2).

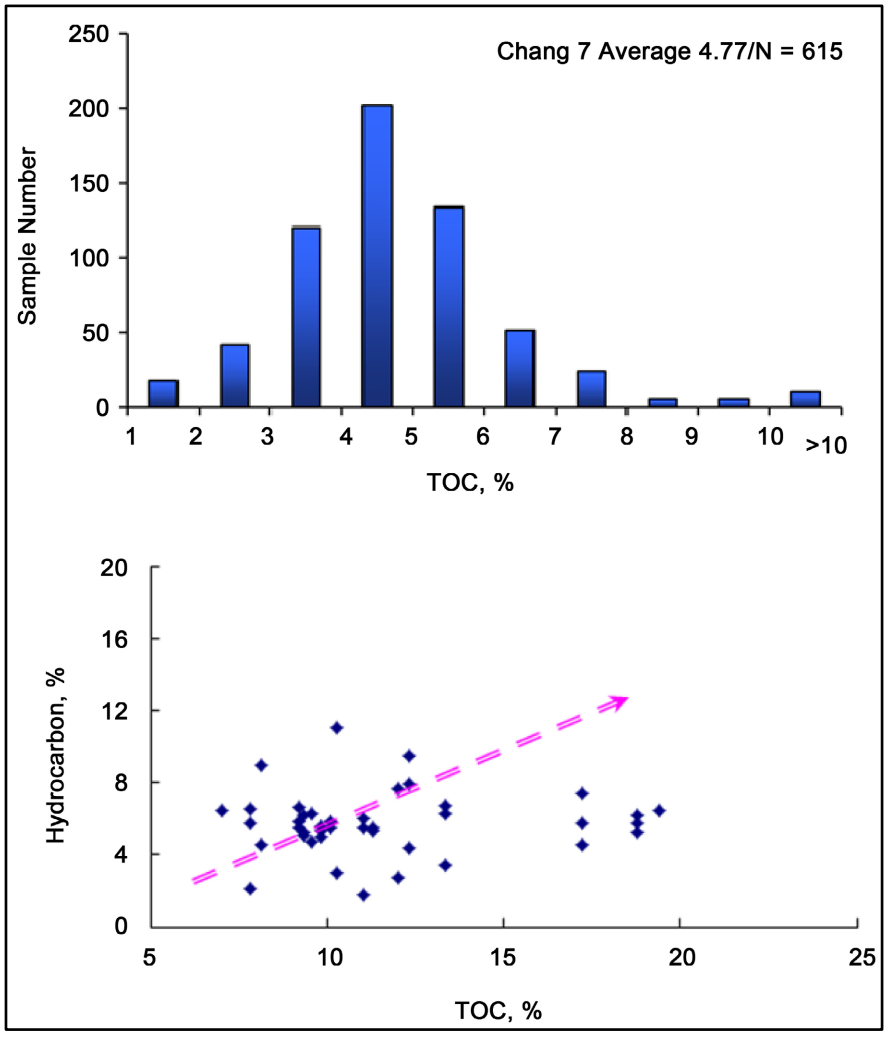

Figure 2. Organic carbon and total hydrocarbon content correlation diagram of Yanchang Formation in the study area.

There is a certain positive correlation between organic carbon content and oil content of shale. On the whole, with the increase of organic carbon content, the oil content of shale increases relatively, and the organic carbon content is usually positively correlated with the hydrocarbon content.

3.2. Organic Matter Maturity

According to the experimental analysis, the maturity of organic matter in the Chang 7 Member of Yanchang Formation in the study area is low. The Ro of the Chang 7 Member shale vitrinite is mainly 0.8% - 1.05%, and the average value of the measured 59 vitrinite reflectance samples is 0.91% (Figure 3). The Chang 7 shale is mainly in the oil window, mainly generating crude oil associated gas and pyrolysis gas.

The content of crude oil associated gas with high maturity will increase. The maximum pyrolysis peak temperature Tmax value of Chang 7 shale in Yanye 22 well is generally between 449˚C - 460˚C, indicating that the organic matter is in the mature stage. With the increase of Tmax value, the hydrocarbon content and the maximum isothermal adsorption gas volume have an increasing trend. Therefore, the maturity of organic matter in the study area is one of the main factors controlling shale oil production (Figure 4).

3.3. Effect of Lithology on Shale Oil Enrichment

For shale reservoirs, physical conditions have a greater impact on shale oil enrichment. Shale reservoirs with large porosity can provide sufficient reservoir space for shale oil enrichment. Reservoirs with large permeability can promote the flow of shale oil and is conducive to the development of shale oil. The physical properties and oil-bearing properties of different lithofacies are quite different. It is believed that the lithology of different fine-grained grades is related to oil content. In fine-grained sedimentary rocks, the lithology of different rock types has different adsorption effects on hydrocarbons. Grey argillaceous siltstone and dark grey silty mudstone have greater adsorption effect on the migrated residual hydrocarbons ($S_0 + S_1$) than black mudstone and black oil shale,

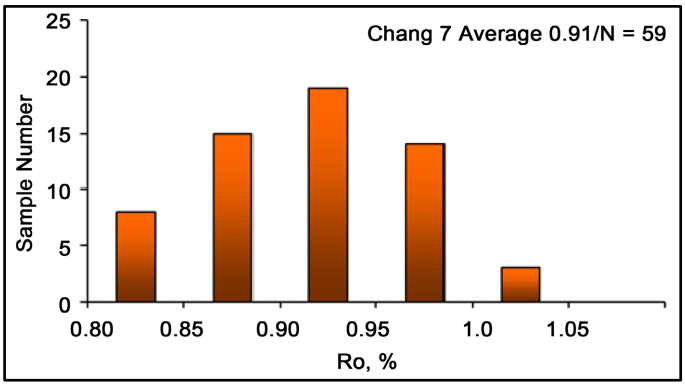

Figure 3. Relation diagram of vitrinite reflectance Ro in Chang 7 member of Yanchang formation.

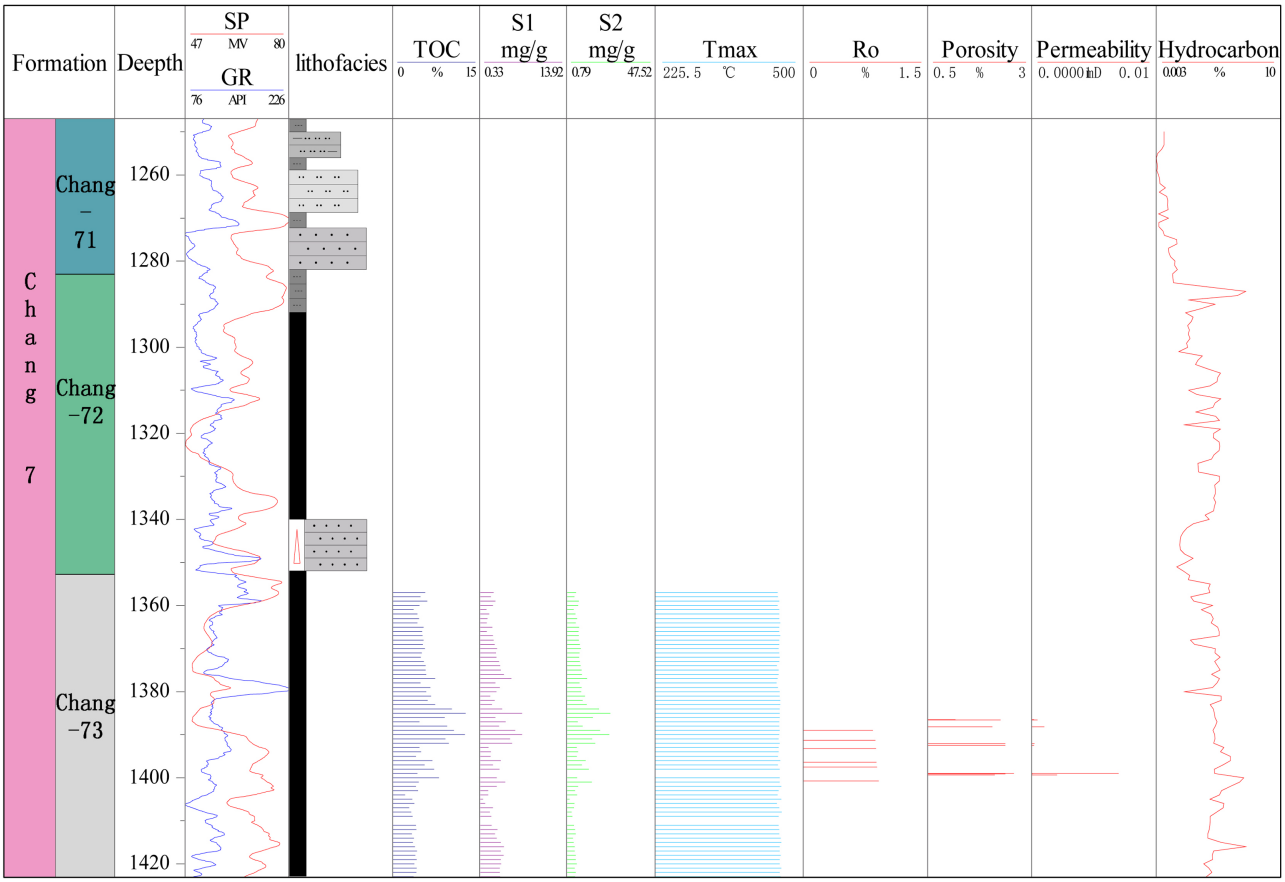

Figure 4. Comprehensive histogram of geochemical characteristics of Chang 7 member.

while mudstone and shale have weaker adsorption effect on residual hydrocarbons. It shows that the content of residual hydrocarbons in rocks has a controlling effect on the content of shale oil, that is, the less the content of residual hydrocarbons in shale, the higher the content of adsorbed gas, such as Yanye 1 well. Gas logging curves in Chang 7_3 black mudstone and black shale show that the total hydrocarbon content is high, that is, the free gas content is high, but the residual hydrocarbon content is low. In contrast, in the upper gray argillaceous siltstone and dark gray silty mudstone, the total hydrocarbon free gas content is low and the residual hydrocarbon content is high. Lithology has a controlling effect on shale oil and gas (**Figure 4**).

3.4. Physical Properties and Fracture Development Degree

The experimental analysis shows that the physical properties of the shale in the Yanchang Formation in the study area are poor. The porosity of the shale in the Chang 7 section is 3.02%, the permeability is 0.15×10^{-3} μm, and the fractures are locally developed. In the fracture development section, the free gas content is very high. In the section with good physical properties, the gas content is high (**Figure 5**). It shows that the development degree of shale physical properties has a controlling effect on shale oil content.

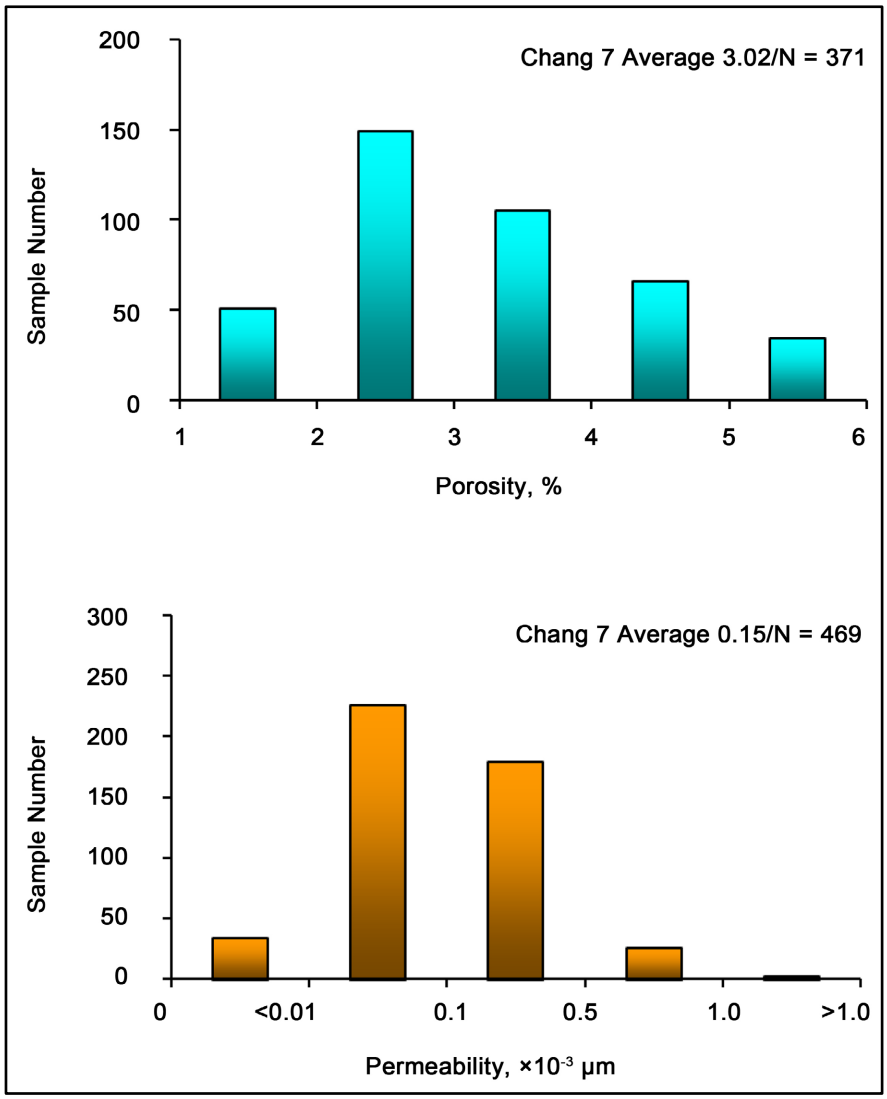

Figure 5. Physical property distribution histogram of Chang 7 shale in study area.

4. Conclusions

1) Organic carbon content, pyrolysis parameters of free hydrocarbons (S_0, S_1) and pyrolysis hydrocarbons (S_2) are positively correlated with shale oil content, indicating that the abundance of organic matter directly controls the content of shale gas, which is the most important controlling factor of shale oil production.

2) There is a positive correlation between vitrinite reflectance Ro and shale oil content, indicating that organic matter maturity directly controls shale oil content, which is the basic control factor of shale oil production.

3) The development degree of shale lithology and physical properties has a controlling effect on the gas content of shale.

Conflicts of Interest

The author declares no conflicts of interest.

References

[1] Jin, Z.J., Zhu, R.K., Liang, X.P. and Shen, Y.Q. (2021) Several Issues Worthy of Attention in Current Lacustrine Shale Oil Explorationand Development. *Petroleum Exploration and Development*, **48**, 1276-1287. https://doi.org/10.1016/S1876-3804(21)60303-8

[2] Jin, Z.J., Wang, G.P., Liu, G.X., Gao, B., Liu, Q.Y., Wang, H.L., Liang, X.P. and Wang, R.Y. (2021) Research Progress and Key Scientific Issues of Continental Shale Oil in China. *Acta Petrolei Sinica*, **42**, 821-835.

[3] Li, Q.W., Ma, X.X., Gao, B. and Chen, X.J. (2021) Progress and Enlightenment of Exploration and Development of Major Shale Oil Zones in the USA. *Acta Sedimentologica Sinica*, **42**, 630-640.

[4] Zou, C.N., Ma, Y.Z., Dong, D.Z., Zhao, Q. and Chen, Z.H. (2022) Formation, Distribution and Prospect of Unconventional Hydrocarbons in Source Rock Strata in China. *Earth Science*, **47**, 1517-1533. https://doi.org/10.3799/dqkx.2022.160

[5] Yin, S.L., Xie, J.Y., Cheng, L.L. and Wu, Y.X. (2022) Advances in Continental Shale Oil Research and Problems of Reservoir Geology. *Acta Sedimentologica Sinica*, 1-23[2022-07-25].

[6] Wu, X.L., Gao, B., Ye, X., Bian, R.K., Nie, H.K. and Lu, F.C. (2013) Shale Oil Accumulation Conditions and Exploration Potential of Faulted Basins in the East of China. *Oil & Gas Geology*, **34**, 455-462.

[7] Wu, X.L. and Mei, D. (2013) Study on Shale Oil Accumulation Conditions in Bohai Bay Basin. *China Petroleum and Chemical Standard and Quality*, **33**, 119.

[8] Zhang, A.D., Wang, J.P., Wang, Y.C., Hong, S.X. and Tan, W.L. (2021) Reservoir Space Types and Oil Occurrence of Gulong Shale in Songliao Basin. *Petroleum Geology & Oilfield Development in Daqing*, **40**, 68-77.

[9] Fu, J.H., Guo, W., Li, S.X., Llu, X.Y., Cheng, D.X. and Zhou, X.P. (2021) Characteristics and Exploration Potential of Muti-Type Shale Oil in the 7th Member of Yanchang Formation. *Ordos Basin*, **32**, 1749-1761.

[10] He, W.J., *et al.* (2019) The Geological Conditions, Resource Potential and Exploration Direction of Oil in Junggar Basin. *Marine Origin Petroleum Geology*, **24**, 75-84.

[11] Fan, B.J., Shi, L., Yang, J., *et al.* (2022) Sedimentary Environment of Lacustrine Organic Matter in the Central Ordos Basin. *Oil & Gas Geology*, **43**, 648-657.

[12] Zhang, Y.X. (2021) Source Rock Characterization: The Dark Mudstone in Chang 7 Member of Triassic, Central Ordos Basin. *Oil & Gas Geology*, **42**, 1089-1097.

[13] Li, S.X., Niu, X.B., Liu, G.D., *et al.* (2020) Formation and Accumulation Mechanism of Shale Oil in the 7th Member of Yanchang Formation Ordos Basin. *Oil & Gas Geology*, **41**, 719-729.

[14] Yang, J.J. (2002) Structural Evolution and Oil and Gas Distribution in Ordos Basin. Petroleum Industry Press, Beijing.