Study on Sedimentary Facies and Reservoir in Taiyuan Formation in Qingshimao area

Fang Hou[1], Li Feng[1], Yue Wu[1], Zhe Zhang[2], Chenyang Wu[2], Xuancheng Zhang[3]

[1]Exploration Division of PetroChina Changqing Oilfield Company;China
[2]School of Petroleum Engineering, Xi 'an Shiyou University, Xi'an, Shaanxi, 710065, China
[3]School of Earth Sciences and Engineering, Xi'an Shiyou University, Xi'an, Shaanxi, 710065, China.

Abstract: Recent exploration results show that there is an industrial airflow in Taiyuan Formation in Qingshimao area of Ordos Basin. The Marine quartz sandstone reservoir developed in Taiyuan Formation is the target reservoir after He 8 and Shan 1 Members in Qingshimao area. In order to study the sedimentary facies characteristics of Taiyuan Formation in Qingshimao area, this paper analyzed the well logging, single well facies and connected well facies on the basis of core observation. In addition, using the data of casting thin section, scanning electron microscope and cathode luminescence, the response relationship between sedimentary facies and well logging facies is established, thus the sedimentary facies in the study area is divided and the reservoir characteristic is studied. The results show that the Taiyuan Formation mainly developed barrier coastal sedimentary facies, which can be subdivided into four sub-facies: marsh, tidal flat, barrier island and lagoon. Lithic quartz sandstone is mainly developed in Taiyuan Formation, followed by quartz sandstone and lithic sandstone. The reservoir space types include intergranular pores, dissolved pores, intergranular pores and micro-fractures. Extra-ultra-low porosity and ultra-low permeability reservoir is developed in Taiyuan Formation in study area.

Keywords: Qingshimao area, Taiyuan Formation, sedimentary facies, reservoir characteristic.

1. Introduction

Through rapid exploration in the Qingshimao area in recent years, multiple high-yield blocks such as Li 56, Li 60, and Li 3-1 have been discovered in the Taiyuan Formation. The neighboring Sinopec Dingbian area has submitted reserves in the Taiyuan Formation, and the Li 3-1 well in the Yumen block has demonstrated good production capacity[1-2]. Exploration indicates that the Taiyuan Formation has developed marine quartz sandstone reservoirs with good homogeneity and gas production capability, making it the most realistic target reservoir after the He 8 and Shan 1 in terms of proven reserves in the Qingshimao area. Recent exploration results show that some exploration wells in the Qingshimao area have shown good industrial gas flow. Therefore, it is urgent to study the sedimentary facies and reservoir of the Taiyuan Formation in this area, analyze the distribution of sedimentary facies, and provide a basis for breakthroughs in oil and gas exploration in the region. However, research on the sedimentary microfacies distribution of the Taiyuan Formation is currently weak, which hinders the progress of exploration evaluation in the area. With the deepening of exploration, five wells have obtained core samples, eight wells have tested gas, four wells have achieved industrial gas flow, and three wells have a daily gas production rate of 20,000 to 40,000 cubic meters in the Qingshimao area south of Habahu Lake, indicating significant oil and gas prospects. In this context, it is necessary to study the sedimentary facies and reservoirs of the Taiyuan Formation in the Qingshimao area[3-5] to provide guidance for future exploration and development.

2. Regional Geological Profile

The Qingshimao area is located in the western part of the Ordos Basin, situated on the first-order structural unit of the Tianhuan Depression and the western margin thrust belt[6-9] (Figure 1). The research area covers approximately 1.28×104 km2. The Qingshimao area experiences complex tectonic movements and has complex reservoir conditions, which have resulted in relatively low exploration levels and limited research on sedimentary facies and reservoirs in the region. The target formation of this study is the Lower Permian Taiyuan Formation, which is located at the bottom of the Lower Permian. It has a thickness ranging from 50 to 100 meters and is primarily composed of medium- to fine-grained sandstones interbedded with gray mudstones and thick coal seams. The top of the Taiyuan Formation is composed of grayish-black mud shale, which is in contact with the overlying Shanxi Formation. The bottom of the Taiyuan Formation is distinguished by the development of the No. 8 coal seam, separating it from the Yanghugou Formation.

3. Sedimentary Facies Types and Characteristic

This study divided the sedimentary facies in the research area based on core observations, well logging, thin sections, and previous research[10-12]. The results indicate that the Taiyuan Formation is mainly characterized by barrier coastline deposits, which can be further subdivided into marsh, tidal flat, barrier island, and lagoon subfacies (Table 1, Figure 2). The marsh subfacies can be further divided into peat flat microfacies, while the tidal flat subfacies can be subdivided into mud flat, mixed flat, sand flat, and tidal channel microfacies. The barrier island subfacies can be subdivided into barrier sand bar microfacies (Table 1, Figure 2).

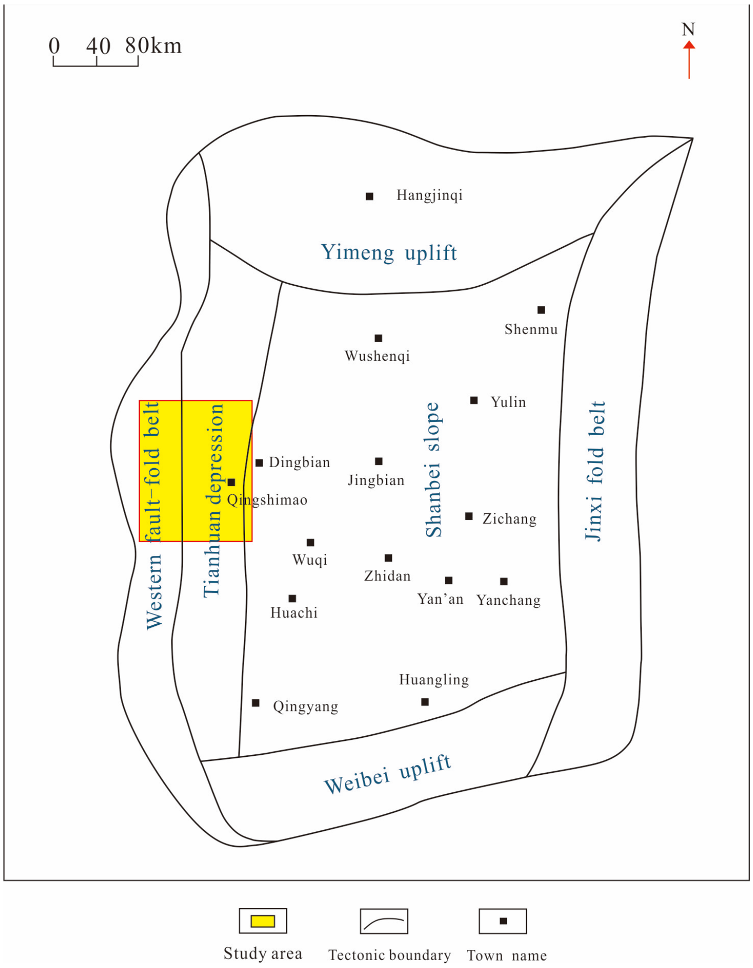


Figure 1. Geographical location map of the study area

Barrier Sand Bar Microfacies: this microfacies is primarily composed of well-sorted fine sandstones and siltstones (Figure 3a). The sand bodies have a thickness of 4-12 meters and exhibit a high degree of sandstone maturity, often cemented by chemical substances. In some areas, the sediment centers of barrier islands have thicker sand bodies, reaching more than 11 meters, generally showing inverse grain sequences and transitioning into underlying mudstones. They exhibit negative gamma-ray anomalies, and the gamma-ray and spontaneous potential curves show smooth, moderately high-amplitude box and funnel shapes (Figure 4a).

Lagoon Microfacies: the lagoon microfacies of the Taiyuan Formation are widely distributed in the study area and primarily consist of black mudstones and carbonaceous mudstones, with minor amounts of grayish-black silty mudstones and muddy siltstones (Figure 3b). Sedimentary structures such as horizontal bedding and ripple marks are visible.

Tidal Channel Microfacies: this microfacies is characterized by gray, medium to coarse-grained sandstones with well-developed upward fining trends. In the study area, the tidal channel microfacies exhibit coarser rock textures, good sorting, and the presence of scouring surface structures. Features such as blocky bedding and wedge-shaped cross-stratification can be observed (Figure 3c, d). The gamma-ray curves often show a serrated box shape (Figure 4b).

Table 1. Sedimentary microfacies division scheme of Taiyuan Formation in the study area

Facies	subfacies	microfacies	Developmental characteristics
Barrier coast	marsh	peat flat	The coal is mainly interbedded with black and dark gray mudstone, and horizontal bedding is developed
	tidal flat	mud flat	It is mainly black and gray black mudstone with horizontal bedding
		mixed flat	It is mainly siltstone and mudstone, lenticular bedding can be seen
		Sand Flat	Gray, light gray fine sandstone, a small amount of siltstone can be seen, parallel bedding, wavy bedding
		tidal channel	Gray, light gray white medium coarse sandstone, vertical vertical rhythm, the bottom of the development of scour surface structure, parallel bedding, block bedding and wedge cross-bedding
	barrier island	barrier sand bar	Light gray white medium fine sandstone, vertical inverse rhythm, local sand body thickness is large, can be seen block bedding, cross-bedding, parallel bedding
	lagoon	lagoon	Mudstone, silty mudstone, limestone, horizontal and wavy bedding can be seen

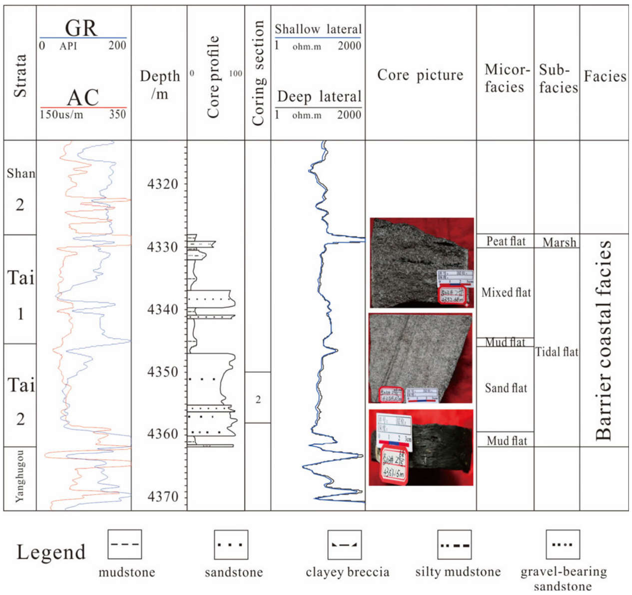
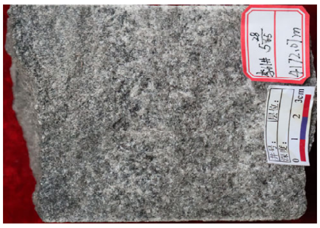


Figure 2. Single well sedimentary facies map of Li 103

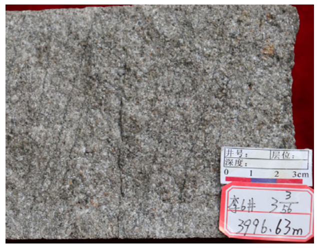
Sand Flat Microfacies: this microfacies is primarily composed of gray and light gray fine sandstones, with minor amounts of medium sandstones. It is interbedded with siltstone and thin layers of mudstone. Parallel bedding and ripple marks are visible (Figure 2). The thickness of the sand varies greatly, ranging from two to over ten meters, with a slightly positive grain sequence (Figure 3e). The gamma-ray values often exhibit a moderately high box or serrated bell-shaped curve, while the thin sandstone intervals show a pointed gamma-ray response (Figure 4c).

Mixed Flat Microfacies: this microfacies is mainly composed of gray and greenish-gray siltstone and mudstone, transitioning upward to black mudstone and coal seams, with localized interbedded layers of marl (Figure 2). Sedimentary structures include flattened bedding, ripple marks, and lenticular bedding, indicative of tidal bedding (Figure 3f). The gamma-ray curve often exhibits a moderate, serrated bell-shaped pattern (Figure 4d).

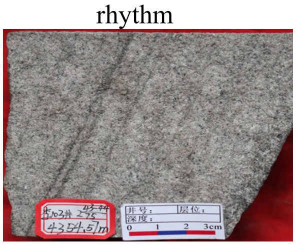


a.Li 61 well，Taiyuan Formation，4172.07m，inverse rhythm

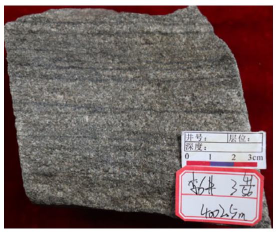
b. Li 100 well，Taiyuan Formation，4092.18m



c.Li 6 well，Taiyuan Formation，3996.63m，wedge cross-bedding



d.Li 103 well，Taiyuan Formation，4354.57m，planar cross bedding



e.Li 6 well，Taiyuan Formation，4002.5m，parallel bedding

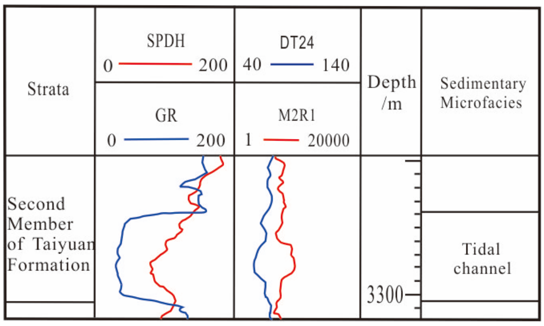
f.Li 17 well，Taiyuan Formation，4201.01m，粉砂岩

g.Li 60 well，Taiyuan Formation，3946.45m，plant detritus

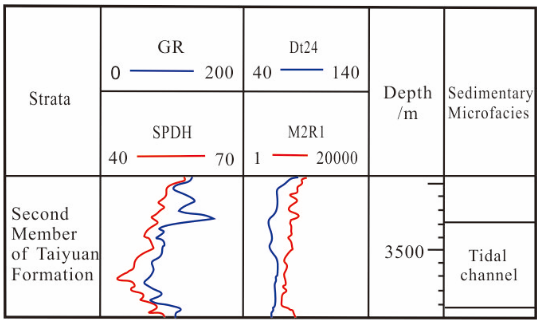
h.Li 91 well，Taiyuan Formation， 4271.63m，coal seam

i.Li 49 well，Taiyuan Formation，3904.75m

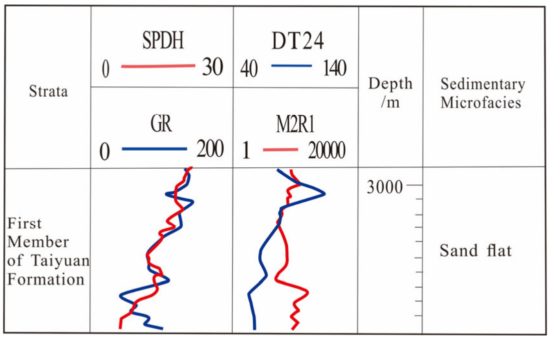
Figure 3. Core photos of the study area



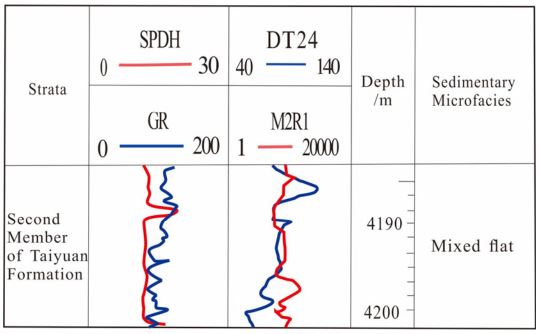
a.Barrier sand bar microfacies logging facies marker



b.Tidal channel microfacies logging facies marker



c.Sand flat microfacies logging facies marker



d..Mixed flat microfacies logging facies marker

Figure 4. Typical logging facies marks in the study area

Mud Flat Microfacies: this microfacies is characterized by the development of thick layers of gray-black and black mudstone, as well as silty mudstone (Figure 2). Occasional thin sandy layers can be observed within the thick mudstone layers, often containing plant debris (Figure 3g).

Peat flat Microfacies: this microfacies is primarily composed of carbonaceous mudstone, gray, gray-black to black mudstone, and sandy mudstone, with interbedded layers of thin mudstone, siltstone, and coal seams (Figure 2). Horizontal bedding, lenticular tidal bedding, and a higher abundance of plant fossils are observed, along with bioturbation structures (Figure 3h, i).

4. Sedimentary Facies Distribution Characteristic

Previous studies have indicated that the study area is primarily characterized by barrier coastline sedimentary environment, further divided into marsh subfacies, tidal flat, barrier island, and lagoon subfacies, which can be further subdivided into peat flat, mud flat, mixed flat, sand flat, tidal channel, barrier sand bar, and lagoon microfacies [13-15].

Based on core observations, single-well sedimentary facies classification was conducted on the cored wells, connected well sedimentary facies profile in the study area was established. This approach allowed for the study of the lateral distribution characteristics of sedimentary facies.

According to the analysis of the connected well sedimentary facies profile of Fadong 1-Liangtan 1-Li 86-Li 63-Su 304 well, the barrier-lagoon subfacies developed in the west of the study area, and the tidal flat subfacies developed in the east of the study area (Figure 5). Laterally, Fandong 1, Liangtan 1, Li 86 and Li 63 developed barrier lagoon subfacies, mainly developing barrier bar microfacies and lagoon microfacies, and the sand bodies of Li 86 and Li 63 were relatively developed. From west to east, Su 304 well developed tidal flat subfacies, with mudflat microfacies developing (Figure 5).

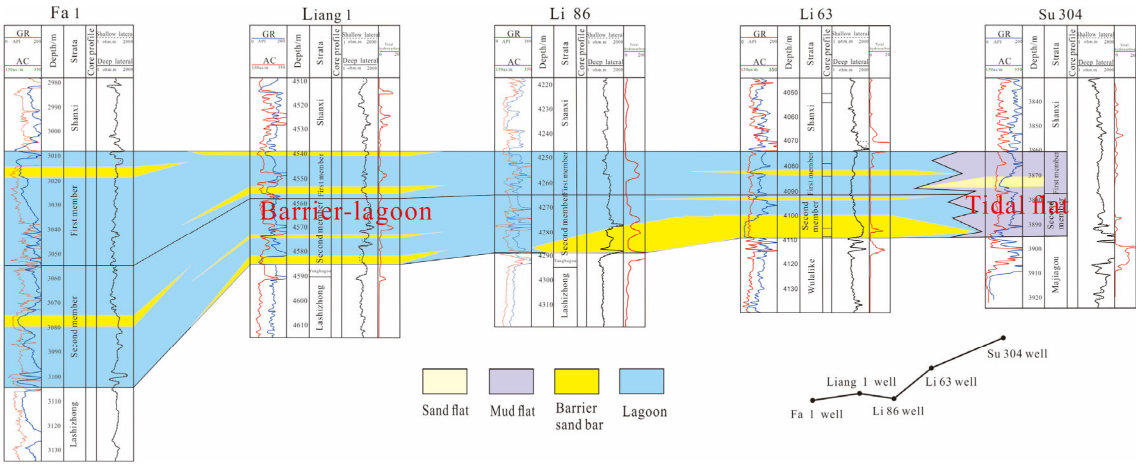
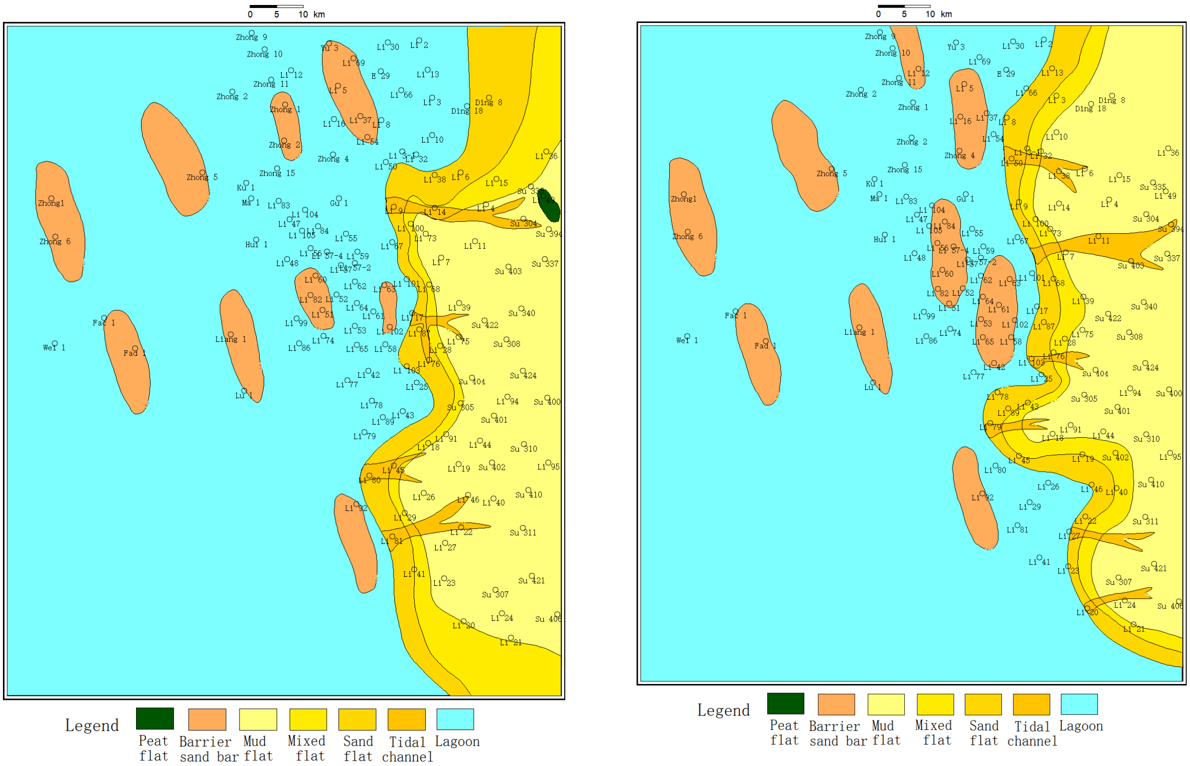


Figure 5. Connected well sedimentary facies profile of Fadong 1well-Su 304 well

Vertically, the development of sedimentary facies is inheritable (Figure 5). From bottom to top, the scale of barrier sand bar becomes smaller, and no barrier sand bar microfacies is developed in First member of Taiyuan Formation of Li 86 well. Tidal flat subfacies developed in Su 304 well, mudflat microfacies developed in Second member of Taiyuan Formation, and sand flat microfacies developed in First member of Taiyuan Formation (Figure. 5).



a Planar distribution map of sedimentary microfacies of Second member

b Planar distribution map of sedimentary microfacies of First member

Figure 6. Planar distribution map of sedimentary microfacies of Taiyuan Formation, Qingshimao area

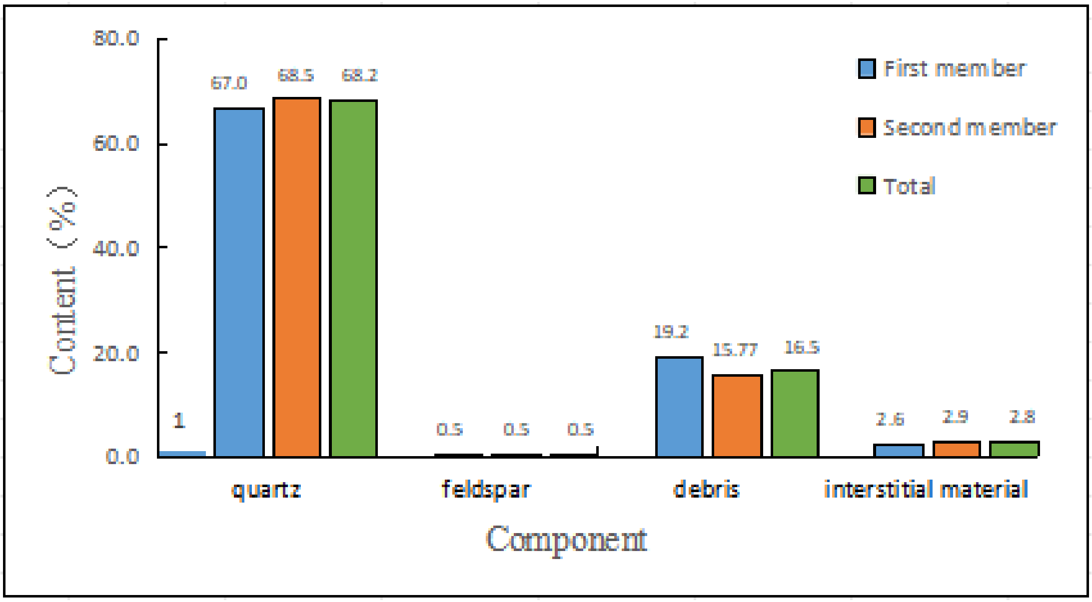
On the plane, the sand layer and stratum ratio data is obtained through statistics and calculation of the data of stratum and sand layer. On the basis of isoline map of each layer of sand layer and stratum ratio, combined with core analysis, logging interpretation, and sedimentary characteristics of single well facies and connected well facies, the spatial distribution characteristics of sedimentary microfacies are studied, and the sedimentary facies plane distribution map is obtained (Figure 6).

The planar distribution map of sedimentary microfacies of Taiyuan Formation in Qingshimao area shows that the barrier coast sedimentary facies of Taiyuan Formation is developed in the study area (Figure 6), with the barrier island- lagoon sedimentary subfacies developing in the west of the study area and the tide-flat subfacies developing in the east of the study area. On the plane, the distribution of sedimentary microfacies is inheritable. The tidal flat subfacies of Second member of Taiyuan Formation is more widely developed, the tidal channel is more developed, the barrier island is more distributed, and the sand body is more widely developed and thicker. First member inherited the sedimentary pattern of Second member. The scale of barrier island sand body in First member is relatively smaller, and the extension range of sand body is smaller. The distribution range of tidal flat subfacies is smaller and the tidal channel development is smaller. The peat flat microfacies is developed in First member of Li 49 well area in the northeast of the study area.

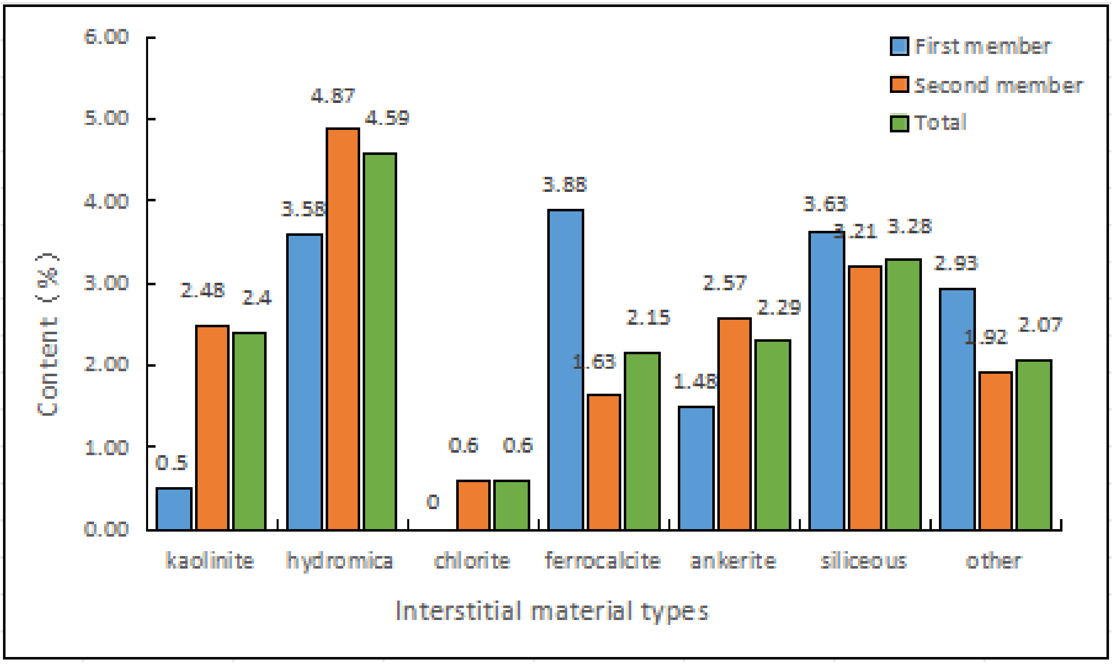
5. Reservoir Characteristic

The reservoir was observed and described through core observation, and the petrologic characteristics of the reservoir were studied in combination with the experiments of casting thin section, cathodoluminescence and scanning electron microscopy [16-18].

According to the statistics of the casting thin section data in Qingshimao area, the Taiyuan Formation mainly develops lithic quartz sandstone, followed by quartz sandstone and lithic sandstone. In the clastic components of sandstone reservoirs, the content of quartz and debris is high, and the content of feldspar is little or not developed (Figure 7a). Among them, the quartz content of First member of Taiyuan Formation is as high as 67%, and that of Second member of Taiyuan Formation is 68.5%. The lithic in First member is 19.2%, and 15.77% in Second member. According to the statistics of interstitial materials in Taiyuan Formation, the interstitial materials in the samples are mainly hydromica, siliceous, iron calcite and iron dolomite, with a small amount of kaolinite and chlorite (Figure 7b). The content of hydromica in First member is 3.58%, while the content of hydromica in Second member is 4.87%.



a Distribution of clastic components of Taiyuan Formation in the study area

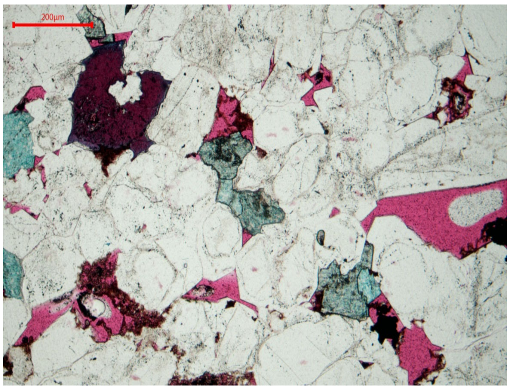


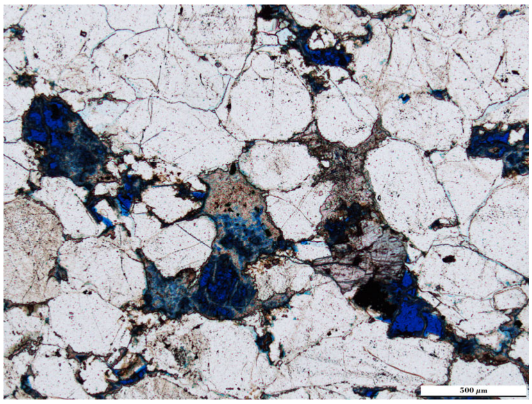
b Distribution map of interstitial content of Taiyuan Formation in the study area

Figure 7. Distribution map of clastic components in Qingshimao area

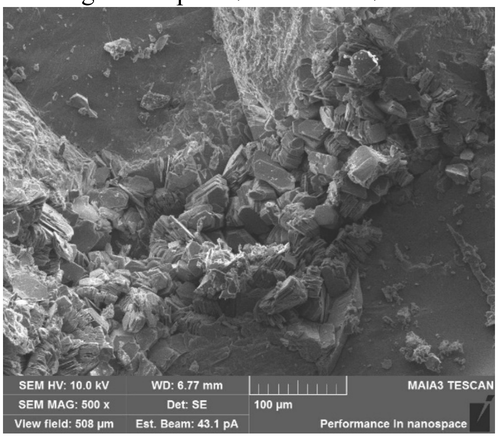
According to petroscopic observation, the reservoir space types of Taiyuan Formation in the study area are mainly pores, and a small number of fractures are developed. Reservoir space types are mainly intergranular pores (Figure 8a), dissolved pores (Figure 8b), intergranular pores (Figure 8c) and other pore types, and cracks mainly refer to micro-fractures (Figure 8d). Intergranular pore is the most important type of reservoir space in Taiyuan Formation.

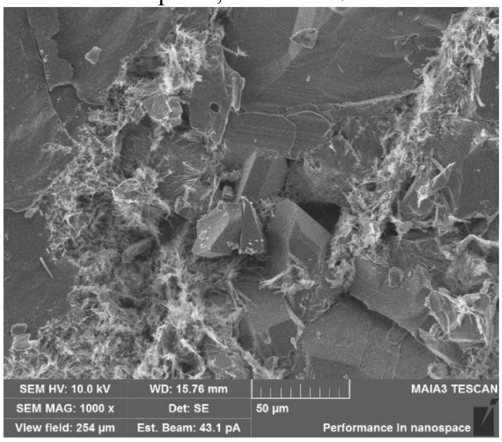
The physical properties of Taiyuan Formation reservoir were tested. 114 samples were selected for porosity test and 381 samples for permeability test (Figure 9). The results show that the minimum porosity of Taiyuan Formation is 1%, the maximum porosity is 9.17%, and the average porosity is 4.54%. The minimum permeability was 0.007mD, the maximum was 0.538mD, and the average was 0.106mD. According to the classification criteria of porosity and permeability, the Taiyuan Formation reservoir in the study area belongs to ultra-low porosity and ultra-low permeability reservoir.





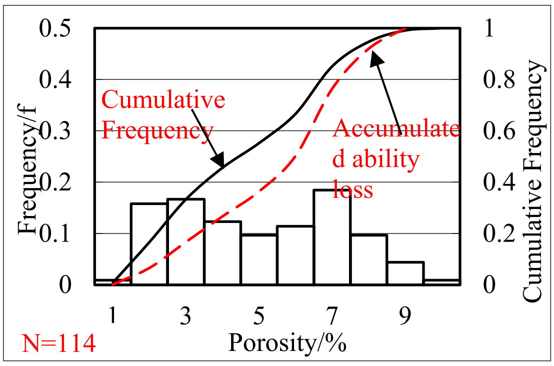
a. intergranular pores，Li 63 well，4105.0m　　b.dissolved pores, Li 17 well，4198.25m



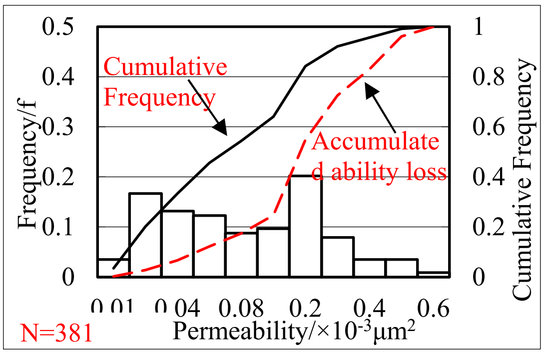


c. intergranular pores，Li 63wel，4106.12m　　d. micro-fracture，Li 38 well，4085.32m

Figure 8. Reservoir space types of Taiyuan Formation in Qingshimao area



The porosity distribution map of Taiyuan Formation in the study area



The permeability distribution map of Taiyuan Formation in the study area

Figure 9. Histogram of reservoir physical property distribution in of Taiyuan Formation, Qingshimao area

6. Conclusion

(1) The Taiyuan Formation in Qingshimao area mainly developed barrier coastal facies, which are further subdivided into four sub-facies: marsh, tidal flat, barrier island and lagoon. Swamp subfacies can be subdivided into peat flat microfacies, and tidal flat subfacies can be subdivided into mud flat, mixed flat, sand flat and tidal channel microfacies. Barrier island can be subdivided into barrier sand bar microfacies.

(2) Vertical, sedimentary facies development has a inheritance, from the bottom to the top, Second member to First member of Taiyuan Formation, the barrier sand bar scale becomes smaller. In the plane, the western part of the study area developed a barrier-lagoon subfacies, and the eastern part developed a tidal flat subfacies.

(3) The reservoir space types such as intergranular pores, dissolved pores, intergranular pores and micro-fractures are mainly developed in Taiyuan Formation. The average porosity and permeability of Taiyuan Formation are 4.54% and 0.106mD, which belong to ultra-low porosity and ultra-low permeability reservoir.

References

[1] ZHAO Weibo, HUANG Daojun, WANG Kangle, et al. Accumulation conditions and key technologies of exploration and development for Qingshimao gas field in Ordos Basin[J]. Acta Petrolei, 2023,44(10):1739-1754.

[2] ZHAI Guanghui. Study on Upper Paleozoic source rocks in western Ordos Basin[D]. Northwest University, 2021.

[3] XUE Chunqi, WU Jianguang, ZHONG Jianhua, et al. Characteristics of the marine-terrigenous interdepositional shale: A case study of Taiyuan formation in Linxing area of

Ordos basin[J]. Journal of China University of Mining and Technology, 2019,48(04):870-881.

[4] SU Dongxu, YU Xinghe, LI Shengli, et al. Sedimentary characteristics and distribution laws of Benxi Fm barrier coast in SE Ordos Basin[J]. Natural Gas Industry, 2017, 37(9):48-56.

[5] LAN Chaoli, ZHANG Junfeng, TAO Weixiang, et al. Sedimentary characteristics and evolution of the Upper Carboniferous Taiyuan Formation, Shenmu gasfield, Northeastern Ordos basin[J]. Acta Geologica Sinica, 2011, 85(4): 533-542.

[6] XU Jing, HE Yonghong, MA Fangxia, et al. Effective reservoir thickness of main oil layer in Dingbian oilfield, Ordos Basin[J]. Lithologic reservoir ,2021,33(5):107-119.

[7] YE Yang, CHANG Yuan. Distribution and formation mechanism of hydrochemical field in Yanchi-Dingbian area of Ordos Basin[J]. Geology and Resources, 2020,29(3):260-265+293.

[8] XI Shengli, GANG Wenzhe, YANG Qingyu, et al. Study on organic geochemical characteristics and sedimentary environment of Chang 7 source rocks in Yanchi-Dingbian area, Ordos Basin[J]. Modern geology,2019,33(04):890-901.

[9] HE Dengfa, BAO Hongping, SUN Fangyuan, et al. Geological structure and genetic mechanism of central palaeouplift in Ordos Basin[J]. Geological science,2020,55(3):627-656.

[10] DING Meng, FAN Tailiang, WU Jun, et al. Sedimentary microfacies characteristics in the high-precision sequence stratigraphic framework of Yijianfang Formation in well T738, Tahe Oilfield, Tarim Basin[J]. Modern geology,2019, 1-25.

[11] XU Minghui, WANG Feng, TIAN Jingchun, et al. Lithofacies division and sedimentary environment of lacustrine organic-rich mudshale: a case study of Chang 7_(3) submember, Ordos Basin[J]. Acta sedimentologica, 2022 ,1-24.

[12] GUO Yanqin, ZHAO Lingsheng, GUO Bincheng, et al. Sedimentary characteristics of Lower Permian in Ordos Basin and surrounding areas[J]. Journal of palaeogeography, 2021,23(1):65-80.

[13] ZHONG Yuting, DONG Yanlei, LI Shunli, et al. Sedimentary characteristics and reservoir control factors of transition facies of Zhuhai Formation in Zhusan Depression[J].Journal of Northeast Petroleum University, 2023,47(4):39-56+106+7-8.

[14] LI Yong, XU Lifu, WU Peng, et al. Facies characteristics and reservoir differences of Marine and continental transitional shale in the eastern margin of Ordos Basin[J].Natural Gas Industry,2023,43(8):38-54.

[15] BO Shangshang, TIAN Jishang, WANG Huatong, et al. Sedimentary environment evolution of transitional facies in Xujiahe Formation, northeast Sichuan Basin: evidence from element geochemistry[J].Natural gas geoscience,1-18.

[16] PENG Lei, SHI Lei, ZHU Yujie, et al. Analysis on micro reservoir characteristics and productivity influencing factors of Taiyuan Formation in Shenmu area, eastern Ordos Basin[J]. Journal of Lanzhou University (Natural Science Edition), 2022, 58(4): 451-457+464.

[17] LIU Tao. Analysis of sandstone reservoir characteristics of Taiyuan Formation in Shenmu-Yulin area, Ordos Basin[J]. Sichuan Journal of geology,2020,40(4):576-580.

[18] GE Dongsheng, CAI Zhenhua, LIU Lingtong, et al. Pore structure and seepage characteristics of tight sandstone reservoir in Tai2 member of Taiyuan Formation, Linxing area, eastern margin of Ordos Basin[J]. Unconventional oil and gas,2020,7(6):11-17.