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Study on Shale Reservoir Characteristics of Wufeng-Longmaxi Formation in Wuxi Area, Sichuan Basin

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Abstract

As a result of the fact that Shale gas exploration in our country is in its starting phase, the geological theory and the exploration and development practice of shale gas is still in the process of exploration. This paper aims at the marine shale of upper Ordovician Wufeng formation and lower Silurian Longmaxi Formation in eastern Sichuan basin. The study adopted the experience from exploration assessment on North American shale gas, based on large amounts of relevant research results at home and abroad and employed relevant documents of field outcrop, core, rock debris, drilling, record, logging, earthquake and analysis test, guided by stratigraphy, sedimentary petrology, unconventional oil and gas geology, geochemistry, petroleum geology and Mineral petrology, combined with regional background. Analyzed the geological characteristics of Wufeng-Longmaxi shale and find out the geological factors which are suitable for the enrichment of shale gas. the assessment of the zone suited for shale gas exploration and the industrialized exploitation of marine shale gas in Eastern of Sichuan Basin.

Keywords

Wufeng-Longmaxi Formation; Sichuan Basin; Marine Shale Gas; Reservoir Characteristics.

1. Introduction

The Sichuan Basin is a huge thick sedimentary basin with relatively complete strata, with multiple petroleum systems developed vertically. In the sedimentary caprock of more than 10,000 meters above the base of the Sichuan Basin, the layers with shale gas exploration potential are the Sinian Doushantuo Formation, Lower Cambrian Qiongzhusi Formation, and Upper Ordovician from bottom to top. Wufeng Formation, Lower Silurian Longmaxi Formation, Upper Permian Longtan Formation, Upper Triassic Xujiahe Formation and Lower Jurassic Ziliujing Formation. Among them, during the Sinian-Middle Triassic marine sedimentation process, five sets of organic-rich shale formed in the Sichuan Basin.

The Wuxi area is located on the outer edge of the northeastern part of the Sichuan Basin. The main structure is located in the middle-east section of the South Dabashan thrust fold belt between the Damping fault zone and the Tiexi-Wuxi concealed fault zone, with typical Jurassic barriers developed Type folds, the Permian-Triassic system is mainly exposed on the surface. From the Late Ordovician to Early Silurian, along with the strong compression of the Cathaysia plate to the Yangtze plate, the ancient land ascended and formed numerous uplifts, forming a large area of semi-closed deep-water

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bays with openings to the north in the Sichuan Basin and peripheral depressions. Sedimentary area; coupled with two large-scale global transgressions during this period, the lack of oxygen and under-compensated water bodies caused by rapid sea level rise eventually resulted in extensive deposition of organic-rich black graptolite shale.

2. Geological setting

The Upper Ordovician Wufeng Formation-Lower Silurian Longmaxi Formation black shale is widely developed in the Sichuan Basin and its periphery. It has the characteristics of large thickness, high abundance of organic matter, and high degree of thermal evolution. It is the key to the exploration and development of marine shale gas. Focus level. In recent years, China has intensified its exploration and development of shale gas, and has achieved commercial breakthroughs in Changning (Changning-Zhaotong), Weiyuan, Fushun-Yongchuan and Fuling Jiaoshiba areas in southern Sichuan, which fully confirms the Sichuan Basin Shale gas is rich in resources and has the conditions to form a good industrial production capacity. However, shale gas exploration in the vast basin margins is relatively lagging, and high-yield gas reservoirs have not yet been discovered, and further basic theoretical research is needed. The Wuxi area in Northeast Chongqing is located on the outer edge of the northeastern part of the Sichuan Basin. It is a new area under preliminary exploration for shale gas exploration. There is a lack of detailed description and description of the characteristics of shale gas reservoirs. The gas-bearing characteristics and influencing factors are still unclear. The understanding of shale gas exploration potential is not clear, which increases the difficulty of selecting favorable target areas and resource evaluation.

3. Characteristics of shale gas reservoir

3.1 Abundance of organic matter

The geochemical characteristics of shale and shale gas is one of the important basic geological issues in the study of shale gas, it is the basis for understanding the formation mechanism and hydrocarbon generation potential of organic-rich shale, and it is also the basis for understanding the genesis, enrichment and accumulation of shale gas. Important theoretical issues. In conventional oil and gas geological research, shale has been used as source rock and caprock in the past. With the continuous deepening of shale research, shale gas has made major breakthroughs in exploration and development. It is now generally accepted that shale It is both a source rock and an oil and gas reservoir, which can form a source-reservoir integrated oil and gas accumulation (Zou Caineng et al., 2013; Zhao Jingzhou et al., 2016; RGLoucks et.al, 2012). Therefore, the organic geochemical index of shale is used as a key parameter of source rock in conventional oil and gas geological evaluation, and as an important basis for shale gas reservoir consideration in shale gas geological evaluation. The geochemical indicators for characterizing and evaluating shale gas reservoirs mainly include: total organic carbon content (TOC), maturity (Ro), kerogen type, phase state of hydrocarbons, gas content and composition, etc. (Wu Jin et al., 2017 ; He Guisong et al., 2020; Zhang Mengqi et al., 2019). This time, the geochemical characteristics of shale gas reservoirs are characterized by three aspects: the abundance of shale organic matter, the type of organic matter, and the degree of organic matter evolution.

Longitudinal: In this study, a total of 46 core samples from the Long-1 sub-member of Well X205 were analyzed for organic carbon. Through analysis, it is found that the total organic carbon content (TOC) of Well X205 has a gradual decrease in the longitudinal direction, with an overall distribution ranging from 1.40% to 5.63%, with an average of 3.30%. The distribution of TOC in Wufeng Group is 2.04%~5.01%, with an average value of 2.93%; 1 sublayer has the highest TOC content, ranging from 3.63% to 5.63%, with an average value of 4.63%; 2 sublayer content is the second, with an average value of 4.11%; 3 layers are distributed between 2.03% and 3.72%, with an average value of 3.13%; 4 layers have the smallest TOC value, which is distributed between 1.40% and 3.86%, and the average value is only 2.98%. (Table 1) The TOC distribution in the Wufeng Formation-Longyi 1

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subsection of Well X202 is between 1.20% and 6.82%, with an average of 3.3%; the TOC of Wufeng Formation is between 2.16% and 5.31%, with an average of 4.1%, which is much higher than that of X205. The TOC content of the Wufeng Formation in Well; the average TOC content of 1-2 layers is 5.0% and 4.7%, which are higher than that of Well X205; the TOC content of layers 3-4 is 3.9% and 4.1%, which is also higher than that of Well X205; overall It reflects that the organic carbon content in the first and second layers of the Long-1 sub-member of the X205 well is the highest, and the gas generation capacity is the best.

On the plane: The organic carbon content (TOC) of the organic-rich shale section of the Longmaxi Formation in Well X205 and the Fengdu-Dazu area is compared. The average organic carbon content is 3.34%, which is similar to that of the neighboring wells X202 (3.45%) and B201 (3.27%). It is less than F202 (3.83) and greater than Z203 (2.46%) in Dazu area. The average organic carbon of the Wufeng Formation is 2.98%, which is less than that of Well X202 (3.25%), Well B201 (4.16%) and Well F202 (4.53%); the average organic carbon of the first layer is 4.63%, which is among all comparison wells The content of organic carbon in the second layer (4.11%) is higher than that of well B201 (3.39%) and the well of Z203 (3.19%) in the Dazu area; the organic carbon content of the third layer (3.13%) is low. In the neighboring area, well X202 (4.03%) and Well F202 (3.76%); the organic carbon content of 4 layers is 2.98%, which is the highest compared with the adjacent well. (Table 1) In general, the organic carbon content at the bottom of the Wufeng Formation and Longyi 1 submember of Well X205 is lower than that of adjacent wells. The overall organic carbon content is medium and the gas generation capacity is not strong.

Table 1. Well X205 and neighboring wells organic carbon content

Well name	Layer name	Max (%)	Min (%)	Average (%)	Sample number
X205	Layer 4	3.86	1.4	2.98	17
	Layer 3	3.72	2.03	3.13	16
	Layer 2	5.29	2.86	4.11	8
	Layer 1	5.63	3.63	4.63	2
	Layer WF	2.98	2.98	2.98	3
X202	Layer 4	5.11	2.93	1.08	17
	Layer 3	1.2	6.8	4.03	7
	Layer 2	2.1	6.4	4.78	5
	Layer 1	4	5.9	5.12	2
	Layer WF	2.16	5.31	3.25	6
F202	Layer 4	2.36	0.44	1.71	21
	Layer 3	4.55	0.79	3.76	18
	Layer 2	5.10	4.04	4.65	6
	Layer 1	5.98	4.99	5.49	2
	Layer WF	3.92	5.59	4.53	8
B201	Layer 4	3.46	0.39	1.85	13
	Layer 3	3.40	2.12	2.66	15
	Layer 2	4.19	2.35	3.39	13
	Layer 1	5.62	4.74	5.29	13
	Layer WF	5.65	0.68	4.16	8
Z203	Layer 4	2.47	0.28	1.52	11
	Layer 3	3.06	0.43	2.34	20
	Layer 2	3.66	2.26	3.19	10
	Layer 1	5.01	2.55	4.74	2
	Layer WF	5.66	0.80	2.16	7

3.2 Mineral composition

Shale is a kind of clay rock, and its material composition is relatively complex. The main mineral types are terrestrial minerals, authigenic minerals and organic matter. The mineral composition

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reflects the material source of the reservoir, and has an impact on the shale gas storage space, gas adsorption, fracture development, post-fracturing fracture formation, and process performance. It is an important content of shale reservoir research (Zhang Chenchen et al., 2017).

3.2.1 Quartz

According to the XRD analysis of the samples from Well X205, the quartz content of Well X205 ranges from 25% to 83%. The Wufeng Formation, layer 1 and layer 2 have relatively the highest quartz content, with the highest value reaching 83% and the average value greater than 50. %, the content of quartz in the 3 and 4 layers is relatively low, and the average value is between 40% and 50% (Figure 1). According to the observation of core, thin section and scanning electron microscope, it can be roughly speculated that there are two main causes of its formation: terrestrial quartz and biogenic quartz. Observed through thin slices under the microscope, the bio-quartz gradually decreases upwards, and the terrigenous quartz increases upwards. The quartz in the shale in the lower Wufeng-Long-1 submember is mainly bio-quartz.

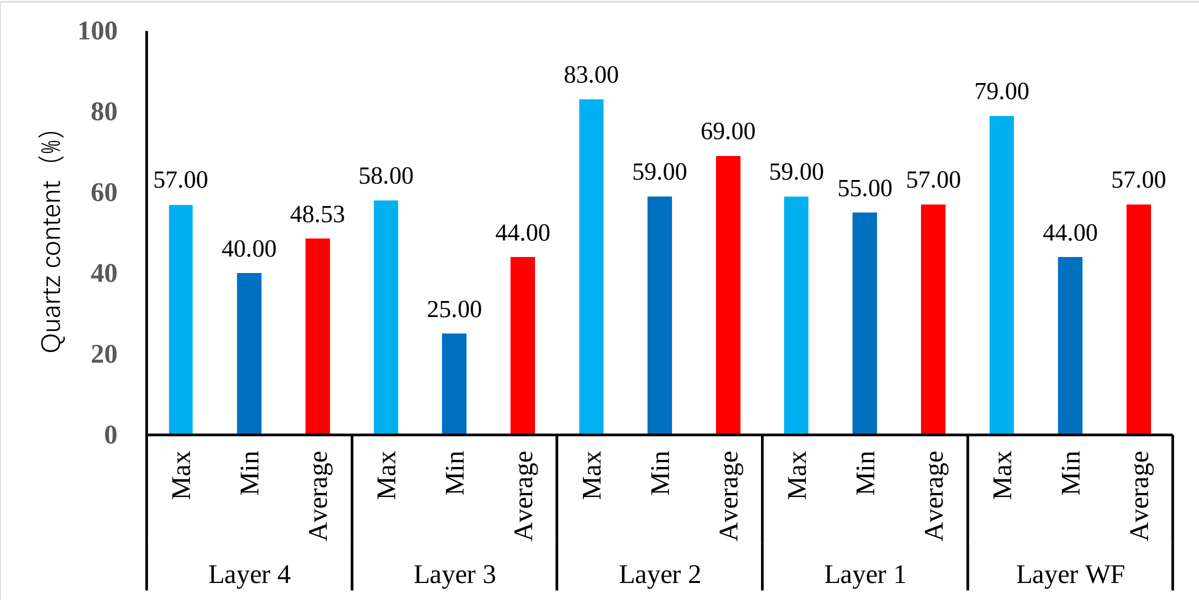

Fig. 1 Distribution histogram of quartz content in each layer of Well X205

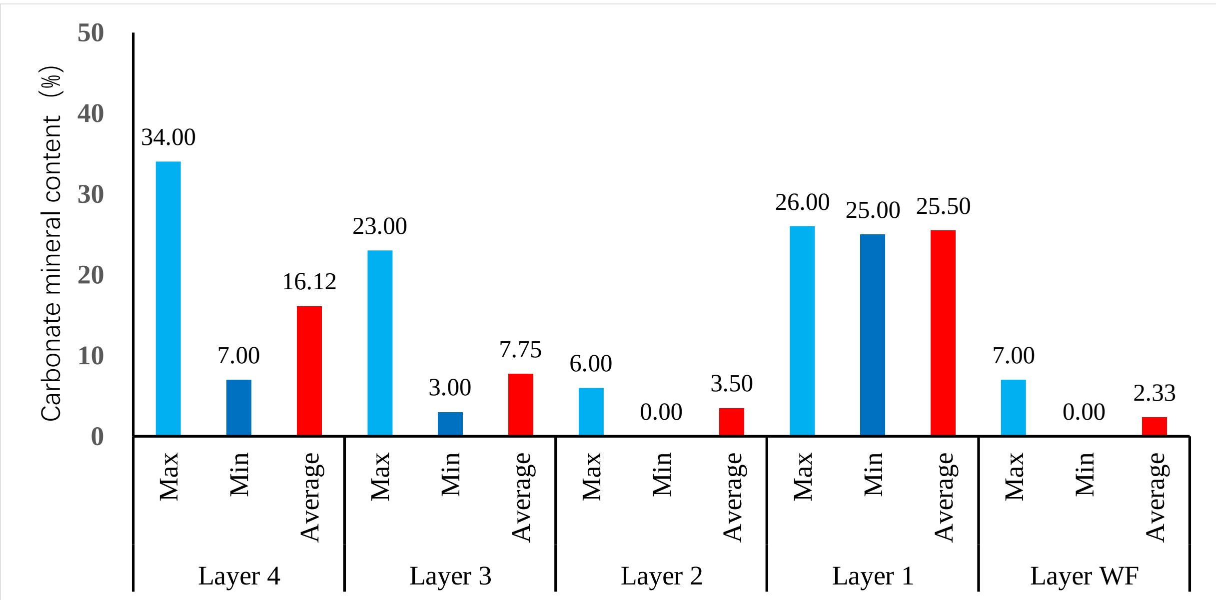

Fig. 2 Distribution histogram of Carbonate minerals content in each layer of Well X205

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3.2.2 Carbonate minerals

The carbonate minerals in this area are mainly calcite and dolomite. The content of carbonate minerals in the first and fourth layers is the highest, ranging from 7% to 34%, with an average of 25.50% to 16.12%. The Wufeng Formation has the lowest carbonate mineral content, ranging from 0% to 7%, with an average value of only 2.33% (Figure 2). Calcite is an unstable mineral, and its intragranular or intergranular dissolution pores can be seen under the scanning electron microscope (Figure 3, Figure 4, Figure 5, Figure 6).

Fig. 3 Well X205, 3259.77m, cracks filled by calcite

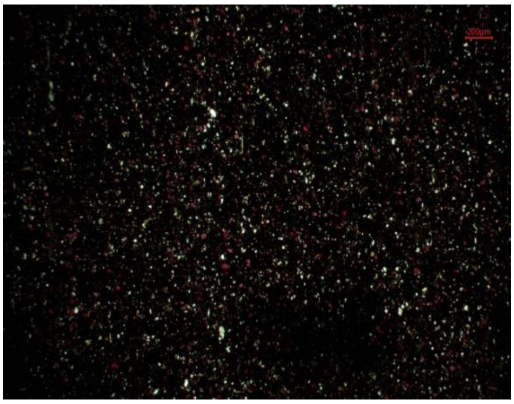

Fig. 4 Well X205, 3265.4m, calcareous shale

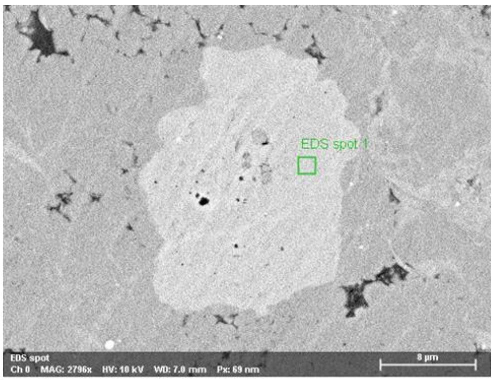

Fig. 5 Well X205, 3255.96m, carbonate minerals

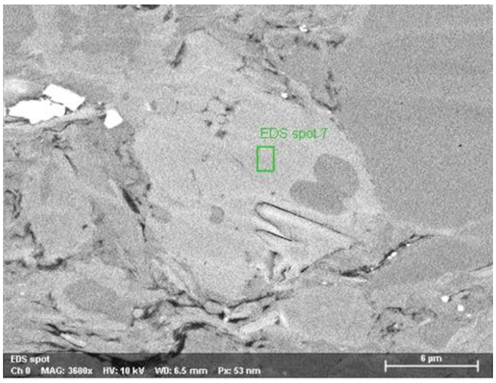

Fig. 6 Well X205, 3243.35m, carbonate minerals

3.3 Pore types and micro-fracture characteristics

3.3.1 Intergranular pores

Intergranular pores are developed between plastic particles and brittle particles in shale. Common plastic particles in shale are mainly flocculent clay minerals, fecal pellets and organic matter; brittle particles are mainly quartz, feldspar, and authigenic pyrite And biological debris. Generally, in shallow buried deposits, intergranular pores are relatively developed and well connected, which can form an effective pore space network. However, as the buried depth increases, formation pressure and temperature increase, diagenesis increases, and intergranular pores continue to decrease. In this process, plastic particles are distorted and deformed under the influence of compaction, which blocks the pore throat, which affects the connectivity between pores, and the dissolution of unstable minerals may also increase the intergranular pore space.

This time through FE-SEM observation and analysis, it was found that the pores between the particles in Well X205 were relatively developed. It mainly develops between brittle particles, between brittle and plastic particles and the edges of brittle particles. Most of the unstable minerals (calcite, feldspar, etc.) and relatively stable minerals are produced by the dissolution of the contact edges, or where

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organic matter and clay minerals are in contact Because organic matter is affected by heat or clay minerals are dehydrated (Figure 7).

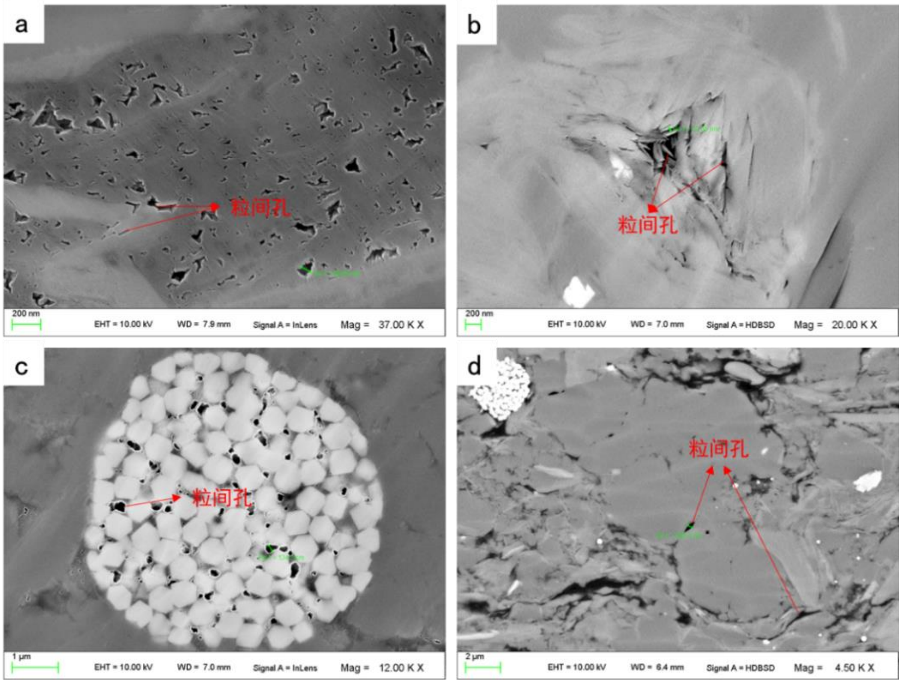

Fig. 7 Intergranular pores of shale in Well X205

a. Well X205, 3264.52m, Wufeng Formation, intergranular and organic pores

b. Well X205, 3255.96m, Longmaxi Formation, intergranular pores and microcracks

c. Well X205, 3255.96m, Longmaxi Formation, pyrite intercrystalline pores

d. Well X205, 3243.35m, Longmaxi Formation, intergranular pores and microcracks

3.3.2 Intragranular pores

The intragranular pores are mainly the pores inside the particles, and the internal pores of local grains are also common. Most of the intragranular pores are formed by diagenesis, and a few are primary. The main types include mold pores (formed by partial or complete dissolution), pores between fossils, intercrystalline pores of berry spherical pyrite, cleavage surface pores inside clay and mica particles.

The intragranular pores developed in Well X205 are mainly clay mineral interplate pores, berry spherical pyrite intercrystalline pores, biological cavity pores, calcite and feldspar intragranular pores. The inner pores of calcite, feldspar, and dolomite are mostly triangular, angular, elongated, dissolved pores and micro-cracks (Figure 8).

3.3.3 Organic pores

The pores developed in organic matter are widely regarded as an important part of the shale gas pore system (Loucks et al., 2009; Ambrose et al., 2010; Passey et al., 2010; Sondergeld et al., 2010b; Curtis et al., 2011a, b; Slatt and O'Brien, 2011; Milliken et al., 2012a). The pores developed in the organic matter are called organic matter pores. The pore morphology of organic matter often appears as isolated pores in two-dimensional space, but it shows good connectivity in three-dimensional space (Jiang Yuqiang et al., 2010). In two dimensions, the shape is mostly irregular, bubble, ellipse, round, honeycomb, etc. The pore diameter of organic matter is between a few nanometers and a few hundred nanometers, and the morphology is mostly round, elliptical, honeycomb, and mostly macropores. The degree of development of organic pores in Well X205 is low, mainly slit-shaped and elliptical, and have certain directional arrangement characteristics, which may be related to the actual pressure relief of the reservoir (Figure 9).

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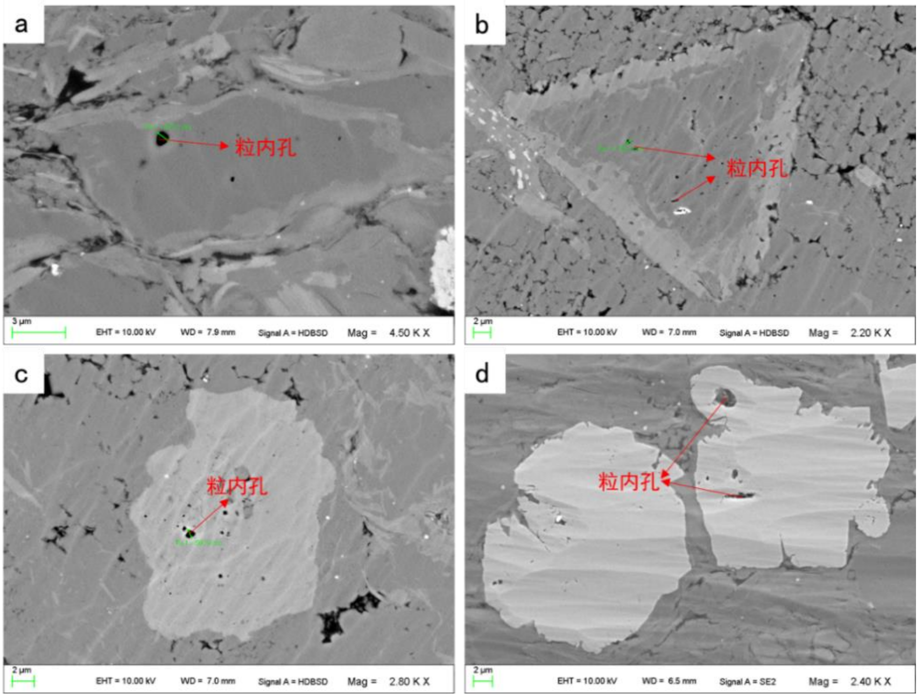

Fig. 8 Intragranular pores of shale in Well X205

a. Well X205, 3264.52m, Wufeng Formation, intragranular pores

b. Well X205, 3255.96m, Longmaxi Formation, intragranular pores

c. Well X205, 3255.96m, Longmaxi Formation, intragranular pores

d. Well X205, 3243.35m, Longmaxi Formation, intragranular pores

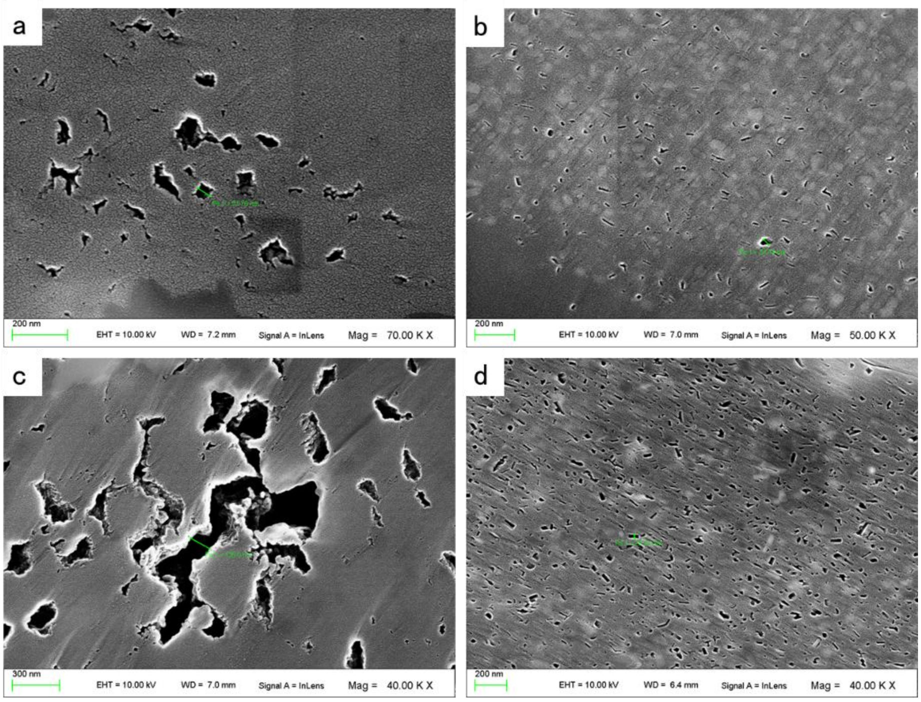

Fig. 9 Organic pores of shale in Well X205

a. Well X205, 3259.77m, Wufeng Formation, organic pores

b. Well X205, 3255.96m, Longmaxi Formation, organic pores

c. Well X205, 3243.35m, Longmaxi Formation, organic pores

d. Well X205, 3243.35m, Longmaxi Formation, organic pores

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3.3.4 Microcracks

Micro-fractures are not only shale gas storage spaces, but also important channels for shale gas seepage. It is conducive to the migration of shale gas from matrix pores to the reservoir through micro-fractures, and at the same time promotes the conversion of adsorbed gas to free gas. The development degree of micro-fractures is related to the direction of fracturing fractures, directly affecting the production of shale gas, and has an important impact on the high and stable production of shale gas in the later stage (Figure 10).

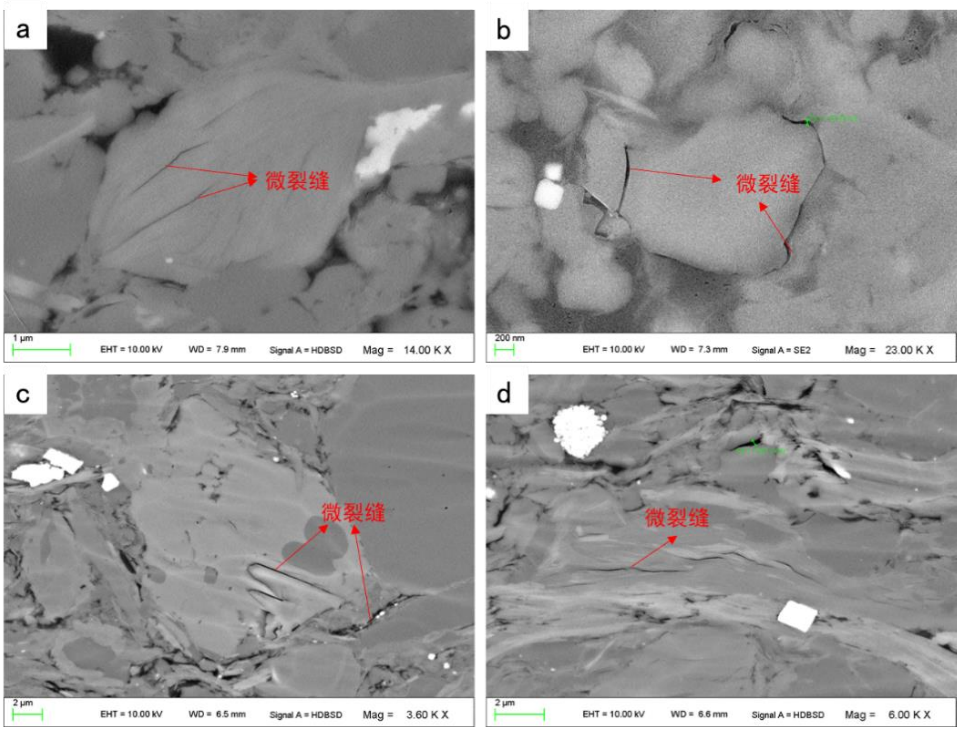

Fig. 10 Microcracks of shale in Well X205

a. Well X205, 3264.52m, Wufeng Formation, micro-cracks

b. Well X205, 3259.77m, Longmaxi Formation, micro-cracks

c. Well X205, 3243.35m, Longmaxi Formation, micro-cracks

d. Well X205, 3243.35m, Longmaxi Formation, micro-cracks

4. Conclusion

(1) The organic matter content of Wuxi area is high, and the organic matter content of one layer is higher than 4%. It has a good material basis and gas generation capacity. However, the thermal evolution degree of organic matter in high-quality shale reservoirs is high, with Ro greater than 3%. FE-SEM analysis show that the organic and inorganic pores of reservoirs in the area are underdeveloped, with poor physical properties and low gas content. The analysis of mineral components shows that high-quality shale has high siliceous content and strong brittleness, which is beneficial to transformation.

(2) Wuxi area is located in the arc-shaped fold belt of Daba Mountain, with strong structural deformation. The shale suffered strong tectonic action in the later stage of accumulation, which caused natural gas to dissipate, resulting in a low formation pressure coefficient and reducing the supporting effect of formation pressure on pore preservation. It is not conducive to the preservation of natural gas. At the same time, the degree of thermal evolution of organic matter is high, and the evolution of organic matter pores is in the stage of deformation and extinction, making the pores

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smaller or even disappearing, resulting in lower reservoir physical properties and gas-bearing properties, and ultimately leading to best reservoirs is the thinnest, which seriously affects the natural gas enrichment of Wuxi area.

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