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LITHOFACIES TYPES AND RESERVOIR DEVELOPMENT CHARACTERISTICS OF CONTINENTAL SHALE IN THE ZILIUJING FORMATION IN NORTHEAST SICHUAN BASIN

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Abstract: The potential of continental shale gas resources in China is huge, and the Lower Jurassic in some parts of northeastern Sichuan has obtained industrial shale gas flow. Carrying out research on shale lithofacies division and reservoir characteristics is conducive to further exploration and development of continental shale gas. The continental shale of the Ziliujing Formation in the Northeast Sichuan Basin was carefully studied by XRD, ordinary thin section, scanning electron microscope, high-pressure mercury intrusion, N2 adsorption and CO2 adsorption. The shale is divided into 12 different lithofacies by taking the abundance of organic matter and mineral composition as classification parameters, and it is found that the shale of the Ziliujing Formation mainly develops four kinds of lithofacies, namely organic-poor siliceous shale (I 3), mixed organic matter shale (IV2), organic siliceous shale (I 2) and organic-rich clay shale (II 1). The characteristics of shale reservoirs of different lithofacies are quite different. Organic matter-rich clay shale has an organic matter content of more than 2%, the best hydrocarbon generation potential, good connectivity between organic matter pores and intercrystalline pores of clay minerals, and a relatively small specific surface area. Large and well-developed laminar structure is conducive to industrial fracturing, and is the optimal continental shale lithofacies, and is the most favorable target for exploration and development of continental shale gas; organic matter-containing mixed shale (IV2) has an organic matter content greater than 1 %, higher pore volume, better gas storage capacity, and the development of layered structures that are conducive to fracturing, it is a good continental shale lithofacies, which is a more favorable target for exploration and development; while the organic-poor siliceous shale (I 3) and organic-containing siliceous shale (I 2) are massive, with low pore volume and specific surface area. They are poor continental shale lithofacies, and are the most unfavorable targets for exploration and development.
Keywords: Northeast Sichuan; Continental shale gas; Ziliujing Formation; Shale lithofacies; Reservoir characteristics

1 INTRODUCTION

In recent years, the unconventional oil and gas revolution has attracted more and more attention around the world, and shale gas, as a clean energy source, has become one of the focuses of unconventional oil and gas exploitation. In southern my country, a series of breakthroughs have been made in marine shale exploration and development in Fuling Jiaoshiba area, Weiyuan area, and Changning area[1,2], and several shale gas demonstration areas have been built for commercial exploitation. No major breakthrough has been made for a long time, mainly due to its strong heterogeneity and large differences in shale lithofacies[3,4]. Lithofacies refers to the rock types and their combinations formed in a certain depositional environment[5-7]. Scholars at home and abroad have carried out a series of work on the division of shale lithofacies, mostly focusing on the marine shale lithofacies. [5] used mineral composition, paleontology, and sedimentary structure as classification parameters to divide Barnett Shale in North America into laminar siliceous mudstone, lamellar clay-bearing limestone, and skeleton argillaceous limestone. Liang Chao et al. [8] Divided the Wufeng Formation-Longmaxi Formation shale in the Sichuan Basin into five types of lithofacies based on mineral composition (limey shale, siliceous shale, silty shale, calcareous shale and common shale), Li Zhuo et al[9] divided the Lower Silurian Longmaxi Formation shale into nine lithofacies by using organic carbon content and mineral composition as indicators. Predecessors have linked different shale reservoir properties by dividing marine shale lithofacies, and compared the mineral composition, geochemical characteristics, pore structure, geological stress characteristics and content of different shale reservoirs using lithofacies as the basic unit. [8,9] found out the differences between different shale lithofacies reservoirs, which provided a geological basis for the exploration and development of marine shale gas in the later stage. However, the depositional environment of continental shale in China is complex and the lithofacies are quite different, which is quite different from marine shale. In view of this, this paper takes the continental shale of the Ziliujing Formation in Northeast Sichuan as the research object, combined with previous research results, Using the whole-rock mineral composition, total organic carbon content and other data, the lithofacies of continental shale can be finely divided, and at the same time, the reservoir differences of different lithofacies combined with the sedimentary structure characteristics and physical properties of shale are analyzed, which is called continental shale. A theoretical basis is provided for the selection of sweet spots in rock gas exploration.

1.1 Geological Background

The Northeastern Sichuan Basin is located in the northeast of the Sichuan Basin, including the Tongnanba Structural Belt in the Northern Sichuan Depression, the Gentle Structural Belt in Central Sichuan, and parts of the Eastern Sichuan Fold Belt[10,11]. Carbonate platform deposition and continental clastic rock deposition formed the current structural framework[12]. Influenced by the Micang-Daba orogeny in Northeast Sichuan, fold-thrust belt-foreland basin binary system developed. structure. The continental shale in this area is developed in the Da'anzhai Member and Dongyuemiao Member of the Lower Jurassic Ziliujing Formation. It is a set of lacustrine sedimentary strata. The semi-deep lacustrine deposits are mainly developed near the center of the lake basin, and there are shell banks outside. The lithology of the Ziliujing Formation is dominated by dark gray mudstone and black shale, interspersed with a small amount of gray siltstone and gray shell limestone, and shell fossils of freshwater organisms are common[13,14].

2 EXPERIMENTAL METHODS AND RESULTS

In this study, a total of 27 core samples were collected, all of which came from the continental shale of the Ziliujing Formation in typical wells in Northeast Sichuan, including 15 cores from the upper Da'anzhai Member and 12 cores from the lower Dongyuemiao Member. Geochemical and petrological experiments were carried out. The determination of the total organic carbon content was completed on the CS230HC carbon and sulfur analyzer of China University of Petroleum (Beijing) according to GB/T 19145-2003. The thermal maturity analysis was based on the SY /T 5124—1995 Statistically completed on Leica DM4500P polarizing microscope and CRAIC microphotometer, the type of organic matter is determined by observing and identifying the morphology and structure of kerogen particles under a microscope under natural light and fluorescence to determine the composition of its source. Mineral crystals have specific X-ray diffraction patterns, and X-ray diffraction can be used to measure the content of the mineral in an unknown sample. The mineral composition analysis experiment in this paper is based on SY/T 5163-2010 in Japan Rigaku TTRIII Multifunctional X-ray Diffraction The high-pressure mercury intrusion experiment, nitrogen adsorption experiment and carbon dioxide adsorption experiment were all completed in Beijing Physical and Chemical Testing Center.

2.1 Geochemical Characteristics

The continental shale of the Ziliujing Formation in Northeast Sichuan is divided into the upper Da'anzhai Member and the lower Dongyuemiao Member. The TOC content of the Dongyuemiao Member is 0.09%-3.10%, with an average value of 1.57%. The content in the middle and lower part of the member is relatively high, up to 3.1% (Table 1), which has good hydrocarbon generation potential. The overall TOC content of the Dongyuemiao Member is higher than that of the Da'anzhai Member, and organic matter shows strong heterogeneity in the vertical direction, with large differences in TOC content at different depths. The test results show that the maturity RO value of shale in Ziliujing Formation in Northeast Sichuan is 1.39%~1.73% (Table 1), and the organic matter maturity of the Dongyuemiao Member in the lower part is higher than that in the Da'anzhai Member in the upper part, which shows that the burial depth increases It can promote the thermal evolution degree of organic matter in shale. The shale is generally in the mature-high mature stage, mainly producing condensate oil and wet gas. The types of organic matter are type II1 and type II2, showing good oil and gas generation potential.

Table 1 Geochemical and petrological test results of shale samples from the Ziliujing Formation

layers	TOC/%	RO /%	Type organic matter	ofPercentage of whole rock minerals/%					
				quartz	Feldspar	carbonate minerals	Siderite	pyrite	clay minerals
Da'anzhai section	0.47~2.44 1.052	1.39~1.46 1.425	II 1	19.3~63.2 40.54	1.1~11.5 5.97	0~50.2 16.13	0~17.7 1.18	0~6.2 1.36	22.6~47.8 34.82
Dongyue Temple Section	0.09~3.10 1.571	1.65~1.73 1.683	II 1, II 2	29.1~74.3 49.13	1~3.8 2.32	0~2.4 0.40	0~18.7 4.23	/	24.7~65.5 43.93

2.2 Petrological Features

The main mineral components of continental shale in Northeastern Sichuan are brittle minerals such as quartz, feldspar, calcite, and pyrite, and clay minerals such as kaolinite, illite, and chlorite. The content of quartz minerals is the highest, averaging 44.36% Around, the quartz content of the Da'anzhai Member is 19.3%~63.2%, the quartz content of the Dongyuemiao Member is 29.1%~74.3% (Table 1), and the quartz content of different depth sections is quite different (Fig. 1), it can be seen that continental shale has strong heterogeneity, and the average content of feldspar in brittle minerals is only 4.35%. Minerals were formed by biological action in layered clastic sedimentary rocks such as shale, reflecting the depositional environment with water, dissolved iron and anoxic conditions at that time. The clay mineral content of the Da'anzhai Member is 22.6%-47.8%, with an average of 34.82%, and the clay mineral content of the

Dongyuemiao Member is 24.7%-65.5%, with an average of 43.93%. The overall content of carbonate minerals is relatively high, and carbonate minerals are abundantly developed in the Da'anzhai Member, with a content of up to 50.2%. It is closely related to the limestone and shell fossils developed in the Da'anzhai Member.

3 LITHOFACIES TYPES OF CONTINENTAL SHALE IN THE ZILIUJING FORMATION

3.1 Lithofacies Classification of Continental Shale in the Ziliujing Formation

Referring to previous schemes for classifying marine shale lithofacies[5-8], combined with the characteristics of shale in the study area, mineral composition and organic matter abundance (TOC) were selected as parameters for shale lithofacies classification in this paper. The mineral composition reflects the petrological characteristics of the shale, and the minerals are divided into three categories according to siliceous minerals (quartz + feldspar), carbonate minerals (calcite + dolomite) and clay minerals, and the triangular analysis is performed using the three minerals as end member method., and divided four types of shale lithofacies with 50% content as the boundary, namely, clay shale (type I), siliceous shale (type II), calcareous shale (type III) and mixed shale (type III) Category IV) [16]. Organic matter is the material basis for shale oil and gas generation. Considering that the abundance of organic matter in continental shale is relatively low and the TOC changes greatly in adjacent rock formations, TOC is used as one of the standards for describing shale lithofacies[9], the shale with TOC>2% is classified as organic-rich shale, the shale with 1%<TOC<2% is classified as organic-containing shale, and the shale with TOC<1% is classified as organic-poor shale. Based on the above, 12 shale division schemes are determined, including organic-rich siliceous shale (I 1), organic-containing siliceous shale (I 2), organic-poor siliceous shale (I 3), and organic-rich clay shale. (II 1), clay shale containing organic matter (II 2), clay shale poor in organic matter (II 3), calcareous shale rich in organic matter (III 1), calcareous shale containing organic matter (III 2), Organic calcareous shale (III3), organic-rich mixed shale (IV1), organic-containing mixed shale (IV2) and organic-poor mixed shale (IV3).

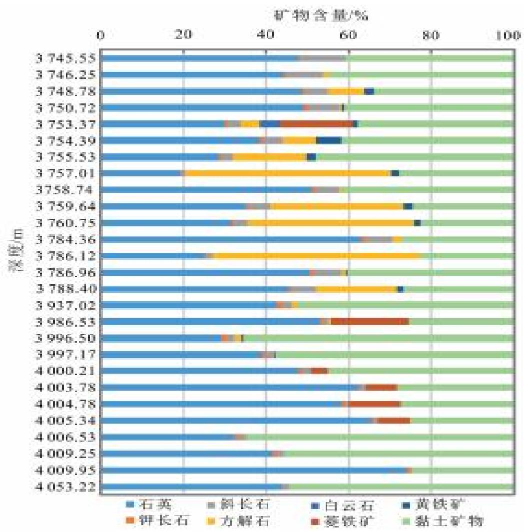

Fig. 1 Whole-rock mineral analysis of Ziliujing Formation shale in Northeastern Sichuan

3.2 Lithofacies Types of Continental Shale in the Ziliujing Formation

According to the above division scheme, the selected 27 core samples from the Ziliujing Formation are mainly divided into four types of lithofacies (accounting for 78%), namely organic-poor siliceous shale (I 3), organic-containing mixed shale (IV 2), The different lithofacies of the continental shale in the Ziliujing Formation reflect the different depositional environments for the organic-containing siliceous shale (I 2) and the organic-rich clay shale (II 1).

3.2.1 Organic-poor siliceous shale (I 3)

This lithofacies is mainly developed at the top of the Da'anzhai Member, and its lithology is gray mudstone with a small amount of interclastic limestone. During the deposition of the Da'anzhai Member, the water body was relatively quiet, and the mud shale was mostly massive. The core color is mainly light gray, and the TOC content The content of siliceous minerals is between 53.08% and 72.64%, with an average of 62.32%, and the content of quartz is 53. About 67%, the content of clay minerals is relatively low, ranging from 27.36% to 46.92%, and the content of carbonate minerals is extremely low, only 1.57% on average (Fig. 1). Large-scale shell beaches[15] were found, and the development of calcareous minerals in this kind of lithofacies is closely related to it.

Fig. 2 Core characteristics of Ziliujing Formation shale in Northeast Sichuan Basin
(a) Da'anzhai member of Well Yuanlu 4, gray mudstone, gray-brown cosclastic limestone, massive structure, buried depth 3 745.38~3 746.56m; (b) Da'anzhai member of Well Yuanlu 4, gray-brown Interbedded bioclastic shale and gray mud shale, layered structure, buried depth 3 757.01~3 759m; (c) Da'anzhai member of Well Yuanlu 4, gray black mud shale, massive structure, buried depth 3 787.77~3 789.52m;
(d) Dongyuemiao section of Well Yuanlu 4, gray-black mud shale, laminar structure, buried depth 3 996.15~3 997.77m

3.2.2 Organic mixed shale (IV2)

This lithofacies is mainly developed in the middle of the Da'anzhai Member, and the lake basin oscillation caused the large-scale contraction and expansion of the lake water[17-19], resulting in the frequent alternation of gray-brown bioclastic shale and gray mud shale [Fig. 2 (b)], obvious bedding can be seen on the core, compared with organic-poor siliceous shale (I 3), the TOC content in it is slightly increased, ranging from 1.01% to 1.94%, with an average of 1. 37 %, the content of carbonate minerals increased significantly between 18.36 % and 41.06 %, with an average of 28 %, the content of siliceous minerals was around 40.9 %, and the content of clay minerals was between 22.96 % and 49 %.02%, with an average of 31.06% (Figure 1).

3.2.3 Organic siliceous shale (I 2)

This lithofacies is developed in both the Da'anzhai Member and Dongyuemiao Member, and the vertical heterogeneity of lithofacies is a major feature of continental shale. Semi-deep lacustrine deposits, the lithology is dominated by mud shale, with occasional silty mudstone interlayers [Fig. 2 (c)], in which the average TOC content is 1.31%, and the siliceous mineral content is 41.87% ~ 68.49%, with an average of 56.49%, clay minerals between 31.5% and 46.67%, with an average of 40.29%, and carbonate minerals only 3.21% left and right (Figure 1).

3.2.4 Organic-rich clayey shale (II 1)

This lithofacies is mainly developed in the Dongyuemiao section, and the structural environment is relatively stable. The lake water range reached its maximum in the early stage, and gradually experienced a process of lake retreat in the later stage[20], and the lithology is dominated by gray-black mud shale [Fig. 2 (d)], in which the TOC content is relatively high, ranging from 2.06% to 3.10%, with an average of 2.59%..50%, the average value is 54.03%, the content of siliceous minerals is 42.52%, and the content of carbonate minerals is about 2.55% (Fig. 1).

4. DEVELOPMENT CHARACTERISTICS OF DIFFERENT CONTINENTAL SHALE LITHOFACIES RESERVOIRS

4.1 Development Characteristics of Laminae

The structural characteristics of shale have an important impact on reservoir performance and gas-bearing properties[21]. Previous researchers defined the horizontal fine layer larger than 1mm as layered structure, and the one smaller than 1mm as laminar structure. Those without obvious bedding are defined as massive structures[22]. As far as the shale of the Ziliujing Formation in Northeast Sichuan is concerned, it is found through microscope observation that the arrangement of bright-colored minerals in the organic-poor siliceous shale (I 3) has less obvious directional characteristics, and the organic matter is unevenly developed and presents a blocky feature[Fig. 5(a)]; mixed organic matter shale (IV2) is layered.

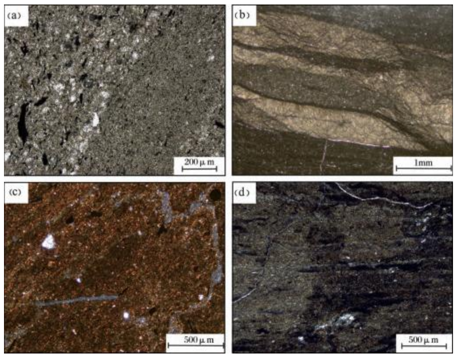

Fig. 3 Microscopic thin-section characteristics of the Ziliujing Formation shale in the Northeast Sichuan Basin

From Figure 3, (a) The Da'anzhai Member of Well Yuanlu 4, organic-poor siliceous shale, with visible quartz bands, buried at a depth of 3 745.38-3 746.56m; (b) The Da'anzhai Member of Well Yuanlu 4, containing organic matter mixture Shale, layered structure, burial depth 3 757.01~3 759m; (c) Da'anzhai member of Well Yuanlu 4, containing organic siliceous shale, laminar structure is not obvious, burial depth 3 787.77~3 789m.52m; (d) Dongyuemiao section of Well Yuanlu 4, rich in organic matter clay shale, laminae developed, burial depth 3 996.15~3 997.77m The belt (light color) is in lateral contact with the mud shale [Fig. 5(b)], reflecting the relatively turbulent water environment at that time; bright-colored quartz minerals are mostly seen in the organic siliceous shale (I 2), and the quartz particles are in the form of Sub-angular, the edges are slightly invaded by clay, etc., and the organic matter is randomly distributed between different minerals, with massive characteristics [Fig. 3 (c)]; the lamellar structure in organic-rich clay shale (II 1) is the most organic matter, quartz minerals and clay minerals are clearly oriented [Fig. 3 (d)], and the density of silty laminae is relatively high, 8/cm, and the width of laminae is about 0.01-0.15mm, and the whole develops continuously along the long axis.

4.2 Pore Structure Characteristics

The characteristics of shale pore structure include pore space distribution, volume, specific surface area, and shape, among which the pore volume directly affects the storage performance of free gas in shale, and the pore specific surface area affects the shale adsorption gas storage capacity. Analyzing the pore structure characteristics of shale is of great significance for studying the gas-bearing properties of shale reservoirs[23-25].

4.2.1 Pore type

The Ziliujing Formation shale in Northeastern Sichuan is rich in pore types, including mineral framework pores, intercrystalline pores, dissolution pores, and organic pores. Organic pores are more developed in organic-rich shale, which is formed by the organic matter in shale during hydrocarbon generation evolution. Observation by scanning electron microscope shows that organic pores are most developed in organic-rich clay shale (II 1). The pore sizes are different, and they are nearly spherical or ellipsoidal, and a few are irregular meniscus and slit-shaped [Fig. 4 (g), Fig. 4 (i)]. There are few organic pores in the organic siliceous shale (I 2) [Fig. 4 (c) - Fig. 4 (e)], and the organic matter is often distributed in strips between minerals and parallel to the development direction of pores and fractures. The stratification is better [Fig. 4 (d)].

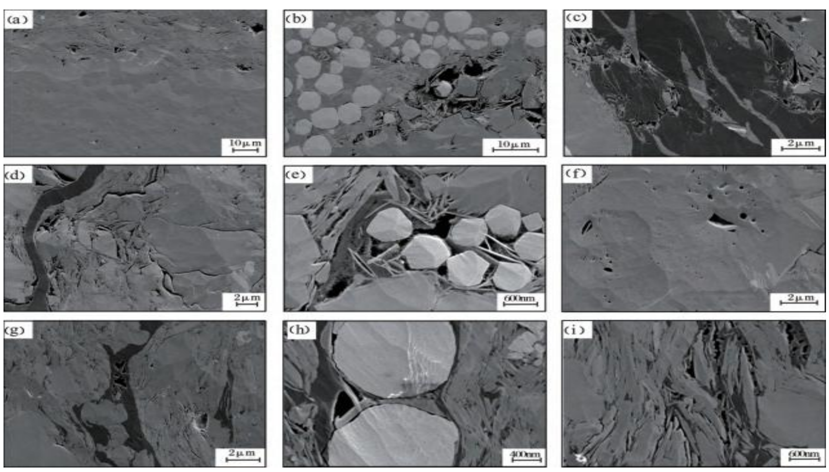

Fig. 4 SEM photo of shale in the Ziliujing Formation in Northeast Sichuan

From Figure 4, (a) Mixed organic shale, with large differences in pore development of different mineral compositions, with a buried depth of 3 754.39 m; (b) mixed organic shale, with pyrite wrapped by clay minerals, with a buried depth of 3 754.39 m (c) Mixed shale containing organic matter, with some dissolution pores around the organic matter, with a buried depth of 3 754.39m; (d) siliceous shale containing organic matter, with layered organic matter, with a buried depth of 3 758.74m; (e) Organic siliceous shale, supported by pyrite, with well-developed intercrystalline pores in clay minerals, buried at a depth of 3 758.74m; (f) organic siliceous shale with elliptical dissolution pores at a buried depth of 3 758.74m; (g)organic-rich clay shale with irregular organic pores and a buried depth of 4 053.22m; (h) organic-rich clay shale with dissolution pores around organic matter and a buried depth of 4 053.22m; (i) organic-rich clay Organic matter pores and intercrystalline pores of clay minerals are more developed in the shale, and intercrystalline pores of clay minerals at a depth of 4 053.22m are common in continental shale, among which organic matter-rich clay shale (II 1) is the most developed. The intercrystalline pores of clay minerals are mainly linear or triangular nanoscale pores, and the organic matter is often associated with clay minerals in the form of organic matter-clay complexes [Fig. 4 (h), Fig. 4 (i)]. The formation of percolation channels greatly increases the connectivity between pores. Organic matter is also associated with clay minerals in mixed organic-matter shale (IV 2) and organic-matter siliceous shale (I 2), but circular pores are rare in organic matter. Pores are developed, only some slit-like and triangular clay mineral intercrystalline pores, and in the organic-containing siliceous shale (I 2), some pyrite particles developed near clay minerals and organic matter are supported between clay minerals, so that the intercrystalline pores of clay minerals are well preserved [Fig. 4 (e)], while some spherical pyrites in the organic-containing mixed shale (IV2) are relatively concentrated, but they are not densely packed, but It is tightly packed by clay minerals, and only local fine sheet-like clay mineral pores are preserved due to the support of pyrite [Fig. 4 (b)].

Mineral framework pores refer to the pores preserved by the mutual support of brittle minerals in the strata during the process of stratum deposition and burial. Among them, the content of brittle minerals such as quartz in the organic-containing siliceous shale (I 2) is relatively high. It can be seen that the intergranular pores formed by the accumulation and support between the minerals and some micro-cracks formed by compaction [Fig. 6(d)] contain organic matter. The mixed shale (IV2) formed a layered structure due to compaction. It can be observed under the scanning electron microscope that the content of quartz and clay minerals in some areas is relatively high. It can be seen that the mineral framework pores are developed, and the carbonate The mineral content is high, and the reservoir is generally tight [Fig. 4 (a)].

Dissolution pores are mostly developed in soluble minerals such as feldspar and carbonate. Dissolution pores can be seen around the organic matter in mixed organic matter shale (IV2) [Fig. 6(c)]. The pores are oval in shape and contain organic silicon. Irregularly shaped dissolution pores can also be seen on the surface of clay minerals and feldspar particles in shale (I 2) [Fig. 4 (e), Fig. 4 (f)]. The connectivity of dissolution pores observed under the scanning electron microscope is relatively Poor, isolated on the mineral surface.

4.2.2 Pore volume and pore specific surface area

Through high-pressure mercury injection, N2 adsorption, and CO2 adsorption experiments, the pore distribution characteristics of Ziliujing Formation shale from nanometer to micrometer scale were obtained, and CO2 adsorption experiment data were selected to characterize micropores ($r< 2nm$), and N2 adsorption experiment data were used to characterize mesopores. ($2nm<r< 50nm$), and high-pressure mercury intrusion experiment data characterize macropores ($r> 50nm$) [23].

The pore volume of continental shale reservoirs in the Ziliujing Formation peaks at 10-1 000 nm, and the pore volumes of organic-poor siliceous shale (I 3) and organic-containing mixed shale (IV 2) are mainly composed of mesopores and macropores. The pore volume of organic-containing siliceous shale (I 2) and organic-rich clay shale (II 1) is generally poorly developed, and the mesopore and macro-pore volumes are only those of organic-poor siliceous shale (I 3) and About half of organic mixed shale (IV 2), the micropore volume of organic-rich clay shale (II 1) is significantly higher than other lithofacies, indicating that although the nanopores developed in organic-rich clay shale (II 1) The pore size is small, but the number is large, and its contribution to the pore volume cannot be underestimated. Comparing the average pore volumes of different lithofacies, it is found that the pore volume of mixed organic matter shale (IV2) is up to 0.025cm3/g. 0.02cm3/g [Fig. 5 (b)], the shale reservoirs are generally tight and the pore volume is small, which may be due to the high content of carbonate minerals in mixed organic matter shale (IV2) is conducive to Mesopores and macropores are developed, for example, many dissolution pores are developed in the carbonate minerals around the organic matter [Fig. 4 (b)]. Produced by the dissolution of particles, etc., to a certain extent, the number of mesopores and macropores is increased, thereby increasing the pore volume.

The specific surface area is mainly provided by micropores and mesopores. Comparing different lithofacies, it is found that the organic-rich clay shale (II 1) has the largest pore specific surface area of 20.82m2/g, and the other three lithofacies have a pore specific surface area of 12m2/g [Fig. 5 (b)], in which the organic-rich clayey shale (II 1) has much more micropores than other lithofacies, with micropores accounting for 80.4% of the total specific surface area, and the other 3 The contribution of the specific surface area of the micropores of this kind of lithofacies is not much different from that of the mesopores. It can be seen that the clay minerals in the organic-rich clay shale (II 1) can provide a large number of interlayer pores and intercrystalline pores, making the number of shale pores Increased, thereby increasing the pore specific surface area of shale.

4.3 Predominant Shale Lithofacies

Traditional marine shale lithofacies studies suggest that the basic conditions for dominant shale lithofacies are: high organic matter abundance and thermal maturity, high brittleness, and low clay mineral content [26, 27], similar to marine shale facies, as the basis of gas-generating substances, organic matter is one of the important indicators to measure the lithofacies of dominant shale. High organic matter content determines the gas-generating potential of shale. Both organic matter-containing shale and organic-rich shale with organic matter content greater than 1% are Meet the standard of dominant lithofacies; on the basis of higher organic matter content, the larger the shale pore volume in the connected pores, the higher the accumulated free gas content, the higher the pore specific surface area, and the higher the adsorbed gas content. It can be seen that the type of storage space and pore structure are also important factors affecting the productivity of shale gas[26]; finally considering the engineering fracturing conditions, the predecessors[28] found based on the research of marine shale that the higher the content of brittle minerals, the more It is beneficial to the later stage of fracturing and the formation of industrial production capacity. In addition to brittle minerals that are prone to cracks when fracturing, the quartz in marine brittle minerals mainly comes from siliceous organisms, which also provide a certain amount of organic matter when they are formed. Therefore, marine authigenic quartz with well-preserved crystal form often has a symbiotic relationship with organic matter, which indicates a better gas generation basis and fracturing conditions, while the continental mineral content cannot be directly used as a favorable indicator for industrial production capacity of engineering fracturing Therefore, for continental shale, on the basis of certain brittle minerals, shale with layered or laminar structure and other weak surfaces for fracturing is selected as the dominant lithofacies, and dominant seepage channels are formed during the fracturing process. This is conducive to improving the productivity of a single well.

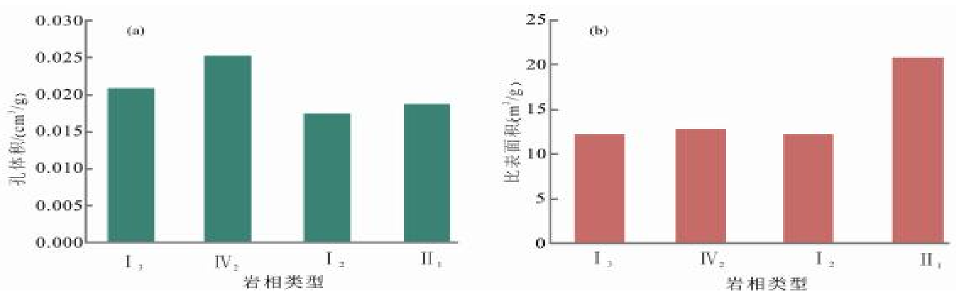

Fig.5 Average pore volume and pore specific surface area of different lithofacies in Ziliujing Formation

At present, the development strata of continental shale gas in northeastern Sichuan are mainly the Da'anzhai Member and Dongyuemiao Member of the Ziliujing Formation. The overall thickness of the Da'anzhai Member is slightly thicker than that of the Dongyuemiao Member. Characterization of developmental types. The research shows that the vertical distribution of shale lithofacies in the Da'anzhai Member has a dichotomous feature. Its upper lithofacies are mainly organic-rich clay shale and organic-containing mixed shale. The organic-rich clay shale (II 1) has an organic matter content greater than 2%, good hydrocarbon generation potential, and an average brittle mineral content of about 45%. At the same time, it has a high laminae development density and a pore specific surface area as high as 20.82 m2/g, which can be regarded as the optimal continental shale lithofacies, and this lithofacies is the main exploration and development target of continental shale gas. Mixed shale containing organic matter (IV2) contains more than 1% organic matter, has a layered structure, and has the highest pore volume of 0.025cm3/g. It is a good continental shale lithofacies and can be used as a sub-favorable continental shale gas exploration development goals. The two lithofacies are vertically interbedded, with thin organic-poor siliceous shale and organic-containing siliceous shale intercalated, reflecting the strong heterogeneity of continental shale. The lithofacies in the lower part of the Da’anzhai Member are mainly organic-poor siliceous shale and mixed siliceous shale, occasionally organic-rich clay shale and organic-containing siliceous shale develop in thin layers. Among them, organic-containing siliceous shale (I 2) has a high content of siliceous minerals, but its pore volume and specific surface area are low, which is not conducive to natural gas storage. It is a medium continental shale lithofacies; organic-poor siliceous shale (I 3) has less than 1% organic matter content, poor gas generation potential, and low pore volume and specific surface area. It is the worst continental shale lithofacies (Table 2), which is not conducive to shale gas development.

Table 2 Comparison of reservoir characteristics of different lithofacies in the continental shale of the Ziliujing Formation

Lithofacies	TOC/%	Structural features	Pore volume/(cm3/g)	Specific surface area/(m2/g)	Evaluation results
Organic-poor siliceous shale (I 3)	<1	lumpy	0.021	12.28	Difference

Mixed shale with organic matter (IV2)	1~2	layered	0.025	12.86	good
Organic siliceous shale (I 2)	1~2	lumpy	0.018	12.21	medium
Organic-rich clayey shale (II 1)	> 2	Lamellar	0.019	20.82	excellent

5 CONCLUSION

(1) The lithofacies of continental shale in the Ziliujing Formation in Northeast Sichuan are mainly divided into four types, namely organic-poor siliceous shale (I3), organic-containing mixed shale (IV2), organic-containing siliceous shale (I2) and organic-rich clayey shale (II 1).
(2) there are some differences in the reservoir characteristics of different lithofacies. The organic-rich clay shale (II 1) develops laminar structures, the organic pores and clay mineral intercrystalline pores are well connected, and the specific surface area is as high as 20.82m2 /g, organic-containing mixed shale (IV2) is layered, with many dissolved pores, and has the highest pore volume of 0.025cm3/g, while organic-poor siliceous shale (I3) and organic-containing siliceous shale (I2) is massive, with many intergranular pores and low pore volume and specific surface area.
Considering the gas generation base, gas storage capacity and engineering fracturing conditions, two types of shale lithofacies were finally selected as the exploration and development targets of continental shale gas, among which organic-rich clay shale (II 1) was the best continental shale. Shale lithofacies with the best hydrocarbon generation potential, large pore specific surface area, and more laminae are favorable for industrial fracturing, and mixed organic matter shale (IV2) is a sub-favorable continental shale lithofacies. The organic matter content is greater than 1%, the pore volume is high, and the layered structure is obvious.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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