Research Article

Differences in Pore-forming Efficiency among Organic Macerals and Its Restriction against Reservoir Quality: A Case Study Based on the Marine Shale Reservoir in the Longmaxi Formation, Southern Sichuan Basin, China

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Organic matter pores are of important significance in the shale formation system rich of organic matters. Although a lot of studies have discussed controlling factors of organic matter pores in the past, it still lacks a quantitative analysis on contributions of organic macerals to organic matter pores. In this study, a case study based on the overmature marine facies shale reservoir in the first submember of the Longmaxi Formation of Silurian in the Weiyuan area was carried out. Besides, qualitative and quantitative identifications of organic macerals and their pore development capacity were provided using the scanning electron microscopy (SEM). The results showed that (1) pore-forming efficiency is one controlling factor over pore development of organic matter. Sapropelinite shows the highest pore-forming efficiency (avg. 38.5%) and while the vitrinite, inertinite, and exinite have the lower pore-forming efficiency. (2) The content of sapropelinite is the highest (avg. 82.4%), and the content of sapropelinite is higher in the Long1 and Long13 layers. (3) The content of sapropelinite has a strong positive correlation with the organic surface porosity. (4) Organic surface porosity, organic porosity, and total porosity present basically consistent variations along the vertical direction of single well. Organic surface porosity restricts the organic porosity which is the dominant type in total porosity. Hence, pore-forming efficiency of organic macerals restricts performances of the reservoir.

1. Introduction

The success of “shale gas revolution” in America has changed the public understanding on pulvetytes, especially shale. People’s understanding on shale is changing gradually from a traditional source rock to be an important reservoir layer [1, 2]. As a self-generation and self-storage unconventional gas reservoir in continuous distributions, shale reservoir is characteristic of low porosity and low permeability, and it is mainly composed of micron-nanometer pore throat systems [3–5]. Shale gas exists in the pores of shale reservoir in the adsorbed state and free state. The pores in the reservoir determine the reservoir capacity, adsorption capacity, and migration capacity of gas [6], thus influencing the ultimate output of natural gas [7, 8].

Pores which are developed in organic matters, hereinafter referred as organic matter pores, are viewed as one of the most extensive pore types in shale reservoirs [9–12]. The development of organic matter pores is obviously restricted by the capability for organic matters to develop
pores. Previous studies mainly focus on influences of total organic carbon (TOC), maturity of organic matter (Ro), organic matter type, asphalt, compaction effect, and mineral composition on organic matter pores [13–23]. However, the controlling effect of organic macerals on the output of organic matter pores has been hardly reported yet. Essentially, organic matters can break the organic surface and develop pores in the large scale as long as they have enough strong expansive forces [13]. As a result, the pore-forming efficiency and structural characteristics of different organic macerals were explored in the present study. Among them, the pore-forming efficiency of different organic macerals (PFEDOM) refers to the ability to develop pores in the four organic macerals of sapropelinite, exinite, vitrinite, and inertinite, respectively. It is measured by the surface porosity of different macerals in a certain period and under certain geological conditions. The sum of the contents of organic macerals multiplied by the pore-forming efficiency can be used to obtain the surface porosity of organic matter, which is a certain amount to describe the development degree of organic matter, and is of general significance. With respect to pore-forming efficiencies of different organic macerals, different scholars reported greatly different results for organic-rich shale in different regions, different eras, and different maturity of organic matters. Moreover, pores in organic macerals were mainly disclosed through a qualitative microscopic observation [24–30].

In this case study, the overmature marine shale reservoir of the Longmaxi Formation in Southern Sichuan Basin was used. Contents of different organic macerals in different samples were gained through a quantitative analysis. Besides, organic surface porosity (pore area inside organic matter/organic surface area × 100%) of samples in the same scale was gained, thus getting the in situ relationship between organic surface porosity and contents of different organic macerals. Pore-forming efficiency controls the organic surface porosity which influences the organic porosity (pore area in organic matter/sample area × 100%). The organic porosity is an important constraint against the reservoir performance. Hence, pore-forming efficiency is a key parameter to evaluate quality of shale reservoir which is rich of organic matters.

2. Geological Setting

In this paper, the Weiyuan area in south Sichuan Basin was chosen as the study area. Tectonically, it locates on the slope belt on the north lower fold belt of palaeomiddle slope in Southern Sichuan Basin. There are relatively flat shale strata [31, 32].

The Sichuan Basin has been generally in the shallow sea environment since the Lower Cambrian. Influenced by ascending currents, a paleogeographic environment in favor of deposition of shale and phosphorus materials has been formed [33]. From the Upper Ordovician-Lower Silurian, the Sichuan Basin was surrounded by the Chuanzhong uplift, Xuefeng uplift, and Qianzhong uplift [34, 35], thus forming a limited retention sea basin environment for source rock development. Finally, the terrain of “three-uplifts and one depression” was formed [36–38] (Figure 1). There were two global transgressions and multistage large-scaled volcanic activities in the Late Ordovician and Early Silurian [39–41]. The deposition region which was represented by Weiyuan formed the Wufeng Formation-Longmaxi Formation shale. Since the early deposition of the Longmaxi Formation, the Weiyuan area generally has been developed in the deepwater shelf sedimentary environment [42] and in the retention quiet anoxic environment [43, 44].

According to data about seismic, borehole core, logging, and production in the exploration region and combining with field outcapping data, the Longmaxi Formation section 1 was further divided into submembers Long11 and Long12. Long11 is mainly the organic-rich shale section where generally has a TOC higher than 2.0%. It is further divided into four layers, namely, Long111, Long112, Long113, and Long114 [45, 46]. Nowadays, Long111 is the target layer for shale gas exploitation in the Weiyuan area and Changning area [47].

3. Samples and Methods

In this study, a total of 13 representative test samples were selected from Long11 of Silurian from wells X1 and X2 in the Weiyuan area, with a depth of 2 640–2 950 m.

In view of the sedimentary fabric characteristics of the shale with very fine grains and strong heterogeneity characteristics, the overall scanning of the sample (25 mm in diameter and 2 mm in thickness) is carried out by using the MAPS (Modular Automated Processing System) scanning technology with a high precision and a large visual area (the physical size of the sample is centimeter). The MAPS divides the sample surface area into a series of regular grids and then scans and forms scanning images for each grid. In this way, a series of two-dimensional high-precision backscattered electron (BSE) scanning images were gained. Subsequently, all images were spliced into a complete two-dimensional high-precision scanning image with a large field of view [52]. MAPS technology is characteristic of large field of view and strong representativeness, without damages to the rock core. The testing method refers to SY/T5162-2014.

The whole test analysis was accomplished in the Laboratory of Reservoir Microstructural Evolution and Digital Characterization of Yangtze University. In the test, HELIOS NanoLab 660 was used as the scanning device. The voltage, current, and pixel size of recognition image and overlapping rate with adjacent small splicing image were 5~35 KV, 0.01~0.4 nA, 5~500 nm, and 6~8%, respectively.

3.1. Pore-Forming Efficiency of Organic Macerals

Since organic matter pores in shale are as small as nanoscale, different organic macerals are positioned from the complete MAPS image, through which single images with the higher resolution (5 nm) were gained. The probe uses the combination of backscattered electron probe and secondary electron probe. The secondary electron images (field emission electron microscope imaging) can display pores more clearly. A total of 120 high-resolution single images of organic macerals were collected, including 52 images of sapropelinite, 8 images of exinite, 30 images of vitrinite, and 30 images of inertinite. Pores in
different organic macerals of single images were extracted by using ImageJ, and the mean was taken to express the pore-forming efficiency of the macerals [53].

3.2. Organic Maceral Content. A statistical analysis on organic macerals was carried out using the scanning electron microscope of MAPS in this study. Core samples with a diameter of 25 mm and a thickness of 2 mm were prepared and scanned at 250 nm resolution. Combining with microstructure, types of organic macerals were recognized and counted [54]. This method not only causes no damages to samples and has the higher precision than the optical microscope but also avoids losses of organic matters in the process of kerogen microscopy operation [55]. Moreover, it can provide an intuitive display of organic matter pores in macerals on the same scale.

3.3. Porosity Data. Binaryzation segmentation of MAPS gray images was performed by the image segmentation technology of ImageJ to divide organic matters and organic matter pores, thus enabling to get the most direct quantitative relationship between organic macerals and organic matter pores. Quantitative characterization parameters, such as the area and diameter of total organic matter pores and total pores, are obtained through an image analysis. Subsequently, influences of organic matter pores on reservoir performance were disclosed. Porosity measuring standards observe SY/T6103-2019. Specifically, porosity parameters of different samples were collected, and the mean of multiple operations by different people was used. On this basis, the statistical errors caused by image factors and artificial factors can be avoided to the maximum extent.

4. Results

4.1. Pore-Forming Characteristics of Different Organic Macerals. Scanning images were observed in the Z-shaped order. The number of observed areas in each sample was larger than 600, and the single area was about 80 μm × 50 μm. It found from abundant scanning images that the development of organic matter pores in shale samples in the study section presented an extremely strong microscopic heterogeneity.
4.1.1. Sapropelinite. Sapropelinite is the absolute dominant organic maceral in the studying section, and it is mainly formed from biodegradation of algae. Sapropelinite has neither fixed morphology nor clear contour. It is mainly flocculent or cloudiness and can adapt its morphology continuously to matrix pores. Sapropelinite generally has very strong flexibility and mobility [15], and it belongs to an amorphous body [56]. According to the qualitative observation results of SEM, there are a lot of pores in sapropelinite, and its porosity generally represents the organic surface porosity of shale in the studying section. Pore sizes are uneven, and the equivalent radius of pores is 5~300 nm. Pores have diversified morphologies, mainly including approximately round, oval, stripes, and irregular shapes (Figures 2(a) and 2(b)). According to image processing, porosity on the sapropelinite surface is 20%~60% (avg. 38.5%).

4.1.2. Exinite. Exinite mainly comes from reproductive organs, epidermis tissues, and secreta of plants. It generally can be divided into sporophytes, keratinophytes, and resins. In the studying section, the exinite content is extremely low, and no pore is recognized through SEM (Figure 2(c)).

4.1.3. Vitrinite. Vitrinite is mainly formed from humification and gelatinization of stems, leaves, and wood fiber tissues of plants. Under the scanning electron microscope, vitrinite has deep colors and clear contours. They are dense, uniform, and flat and distribute as bulbs or stripes with different widths [57]. In the studying section, there is a low vitrinite content. Under the microscope, there are no pores, few pores, or nearly round nanoscale pores. The equivalent radius of pores in vitrinite is mainly 5~100 nm (Figures 2(d)–2(f)), and the surface porosity is 0%~22% (avg. 6.3%).

4.1.4. Inertinite. Inertinite is mainly formed by fusinization of lignocellularus of plants. The fusinite is the most common maceral. The image is relatively bright under a microscope. The longitudinal section of fusinite is fibrous, and fusinite is in bedding arrangement [58]. In the studying section, inertinites are mainly pore-less or have few elongated organic matter pores. These organic matter pores are mainly consistent with the bedding direction of fusinite (Figures 2(g) and 2(h)). The surface porosity is 0%~15% (avg. 5.2%).

4.2. Organic Maceral Content and Distribution. In this study, organ maceral types were distinguished by combining SEM images and morphological features of maceral. Besides, a microscopic count statistical method of equidistance was applied for a quantitative statistics (Point Counting) of organic macerals in SEM images [54]. The effective statistical area of each sample region is larger than 121 (Figure 3), and the single area is 512 μm × 442 μm. On this basis, organic macerals and relevant contents in samples were gained (Table 1 and Figure 4).

According to organic maceral content data of Long1, in X1 and X2 well (Table 1), the sapropelinite content is the highest in the studying section, which reaches 82.4%. Moreover, sapropelinite content is relatively higher at Long1,1 and Long1,4, but it is relatively lower at Long1,2 and Long1,3. There is an extremely low exinite content, which is 3.1% in average. The mean vitrinite content is about 8.6%, and its content is relatively higher at Long1,1 and Long1,4. The mean inertinite content is about 5.8%. There are a lot of sapropelinite that indicates aquatic organisms like algae in the section, but the contents of exinite, vitrinite, and inertinite which relatively indicate terrestrial microorganisms are extremely low [59]. Based on the characteristic analysis of biomarkes, Zhang et al. believed that algae parent material played an important role in organic matters of Longmaxi Formation shale in southern Sichuan Basin [60] and obtained a consensus with the above conclusion.

This is mainly because during the Wufeng Formation in the Upper Ordovician–Longmaxi Formation in the Lower Silurian, the Weiyuan area was in a closed environment of “three uplifts and one depression” (Figure 1). In this period, there were weak hydrodynamic forces and strong reducibility as well as inputs of ocean currents, volcanoes, and terrestrial nutrients [61–63]. Meanwhile, Ye et al. carried out a lithogeochemical analysis on Long1 in the peripheral region and found that U/Th was extremely high in Long1,1. It was decreased in Long1,2, increased in Long1,3, and the lowest in Long1,4. In this period, there were twice rises and falls of sea surface [64].

During the first quick rising of sea surface, the Longmaxi Formation began to sediment, when there is deep water body, weak hydrodynamic forces, and strong reducibility. Based on the organic isotopic analysis, Zhang et al. believed that organic matters of source rock were stored well due to the sea surface rising and the deepwater reducing environment [65]. Besides, the deep water body restricted large-scaled injection of terrigenous matters [66]. Hence, there were few organic matters that indicate terrestrial sources in this layer. Influenced by ocean current and volcanic activities, a lot of nutrients and reducing gases were brought in to make large-scaled enrichment of algae and other organisms. Consequently, the sapropelinite content in Long1,1 was high.

The Long1,1 was formed after the first falling. The water depth decreased, and the terrigenous matter content was higher than that in Long1,1. The terrestrial organic content increased. As a result, vitrinite and inertinite contents were higher than those of Long1,1. Besides, deep seawater and surface seawater were mixed, which caused damages to the bottom hypoxia environment and formed a weak reducing environment. Consequently, the organic storage conditions in Long1,2 were weakened.

Long1,3 was in the end of second sea surface rising, when there is a low terrigenous matter content and good organic storage conditions. Long1,4 was in the end of second falling, when there is a high terrigenous matter content and poor organic storage conditions. After twice global sea surface rising and falling, sedimentation of four layers of Long1 was formed (Figure 5). There were great differences among layers due to their varying origins. Therefore, organic maceral contents have different vertical distribution patterns of single well.

4.3. Distribution Characteristics of Organic Matter Pores. SEM images of shale samples were collected. Computer processing of shale pores and matrix was performed based
Figure 2: SEM images of organic macerals. (a) Organic matter pores in sapropelinite of X1 well (Long1, 2746 m) are mainly stripes. (b) Organic matter pores in sapropelinite of X1 well (Long1, 2746 m) are round and oval, with uneven size and dense distributions. (c) Resins are mainly formed by resin, gum, waxiness, and fatty secretions of plants, and no pores of X2 well (Long1, 2923.2 m) are observed in organic matters. (d) There is no pore in vitrinite of X2 well (Long1, 2923.2 m). (e) Secondary electron image of vitrinite in well X1 (Long1, 2742 m) shows plenty of nanoscale pores in organic matters, and a large number of round to elliptical organic matter pores are observed on the left side. (f) Partial enlargement of Figure 2(e). After image processing, the pore throat diameter concentrates at 24 nm. (g) The inertinite in the X2 well (Long1, 2923.2 m) is a fusinite, and there are long strip organic pores in the organic matters. (h) There are long strip pores in sapropelinite on the left side of well X1 (Long1, 2721.6 m), but no pores in inertinite on the right side.
on the image analysis software, thus getting distributions of organic surface porosity and organic porosity along vertical direction of single well (Table 1 and Figure 6), specifically:

\[
\text{organic surface porosity} = \frac{\text{pore area inside organic matter}}{\text{organic surface area}} \times 100\%
\]

\[
\text{organic porosity} = \frac{\text{pore area inside organic matter}}{\text{sample area}} \times 100\%
\]

The total area including particles + matrix + cement + organic matter + pores) \times 100%.

According to organic surface porosity and organic porosity of Long1 of X1 and X2 wells (Table 1), organic surface porosity in the studying section is about 18.5% ~ 37.0% (avg. 31.1%). According to vertical distribution of organic surface porosity along single well, the highest porosity is in the Long1_1 content, while porosities of Long1_2 and Long1_3 are relatively lower. There are factors that influence vertical fluctuations of organic surface porosity: contents of different organic macerals are different in different layers, and the pore-forming capacity of different organic macerals varies.

Organic porosity is about 0.9% ~ 3.4% (avg. 2.1%), which is generally consistent with vertical distribution of organic surface porosity along the single well. For the organic matters, there are some factors that influence the vertical fluctuation of organic porosity. Firstly, organic storage conditions of different layers are different, and if the relative content of organic matters in samples is the higher, the organic porosity is relatively higher. Secondly, contents of

| Well | Layer | Depth/m | Sapropelinite/% | Organic maceral | Organic surface porosity/ | Organic porosity/ | Total porosity/% |
|------|-------|---------|-----------------|-----------------|-------------------------|-----------------|-----------------|
| X1   | Long1_1 | 2721.6  | 73.1            | 2.4             | 12.8                    | 11.7            | 18.5            |
| X1   | Long1_1 | 2728.5  | 84.4            | 1.7             | 6.8                     | 7.0             | 36.0            |
| X1   | Long1_2 | 2734.2  | 87.2            | 1.3             | 4.2                     | 7.2             | 32.4            |
| X1   | Long1_3 | 2737.6  | 79.1            | 4.1             | 12.5                    | 4.2             | 33.7            |
| X1   | Long1_4 | 2738.7  | 77.6            | 2.0             | 11.1                    | 9.3             | 29.7            |
| X1   | Long1_2 | 2742.0  | 73.1            | 2.6             | 18.2                    | 6.0             | 28.2            |
| X1   | Long1_1 | 2746.0  | 79.9            | 3.8             | 11.6                    | 4.6             | 36.7            |
| X1   | Long1_1 | 2748.0  | 93.7            | 1.6             | 4.6                     | 0.1             | 37.0            |
| X2   | Long1_2 | 2923.2  | 74.3            | 10.7            | 7.8                     | 7.2             | 23.1            |
| X2   | Long1_3 | 2936.1  | 85.1            | 3.2             | 4.9                     | 6.8             | 33.7            |
| X2   | Long1_4 | 2943.6  | 84.1            | 1.6             | 8.7                     | 5.6             | 26.5            |
| X2   | Long1_1 | 2945.9  | 89.0            | 2.4             | 3.4                     | 5.2             | 34.8            |
| X2   | Long1_1 | 2946.7  | 90.7            | 2.6             | 5.7                     | 0.9             | 34.1            |

Figure 3: Statistical schematic diagram of equidistance based on MAPS images of X1-8 sample (partially).

Table 1: Organic maceral contents and porosity of samples from X1 and X2 wells.
Figure 4: Distributions of organic macerals from X1 (a) and X2 (b) along the vertical direction of single well.

Figure 5: Sedimentary development mode of Long1 1 submember in the Weiyuan area (modified after [64]). (a) Long1 1 4 layer. (b) Long1 1 2 layer. (c) Long1 1 3 layer. (d) Long1 1 4 layer.
organic macerals are different in different layers, and pore-forming capacities of different organic macerals are different.

This study is influenced by resolution of SEM. It is difficult to have a statistics on pores smaller than 5 nm. The practical porosity is larger than the statistical value.

4.4. Organic Matter Pores and Reservoir Performances. SEM images of shale samples and computer processing shale pores and matrix were performed by using the image analysis software. Therefore, total porosity and organic porosity and their distributions along the vertical directions of single well were gained (Table 1 and Figure 7), specifically, total porosity = pore area/sample area × 100%.

According to total porosity of Long11 of X1 and X2 wells (Table 1), the total porosity in the studying section is about 1.3%~4.6% (avg. 2.9%). Vertical distributions of total

**Figure 6**: Distributions of organic surface porosity and organic porosity along vertical direction of single well X1 (a) and X2 (b).

**Figure 7**: Distributions of organic porosity and total porosity along vertical direction of single well X1 (a) and X2 (b).
Porosity and organic porosity along single well are highly consistent. Similarly, total porosity and organic porosity are the highest in Long1_1. The total porosity in Long1_2 and Long1_4 is relatively low. Moreover, the proportion of organic porosity in total porosity is relatively high, which generally is higher than 50%. Organic porosity is the major component of pore space in shale reservoir in the studying section.

5. Discussions

In the study area, development of organic matter pores in shale samples from the Longmaxi Formation has extremely strong microscopic heterogeneity. Macerals were recognized under a microscope, and pores in macerals could be seen intuitively. Meanwhile, pores in different macerals were extracted quantitatively, thus getting the average surface porosity. To sum up, the pore-forming efficiency of sapropelinite is the highest in the studying section, while pore-forming efficiencies of vitrinite and inertinite are relatively lower. There is an extremely lower exinite content (Table 2).

According to vertical distributions of different organic maceral contents, organic surface porosity, organic porosity, and total porosity in a well, it finds consistency among organic surface porosity, organic porosity, and total porosity in term of vertical variations in single well. Moreover, such vertical variations are consistent with the variation of the sapropelinite content. They are all higher at Long1_1 and Long1_3, but lower at Long1_2 and Long1_4.

According to the quantitative analysis of organic maceral contents and organic surface porosity, it concludes a strong relationship between sapropelinite content and organic surface porosity in the studying section. With the increase of sapropelinite content, porosity inside organic matters is increasing gradually (Figure 8). $R^2 = 0.4946$ is indicating a weak correlation. The correlation between porosity in

| Organic macerals | Pore-forming efficiency | Porosity characteristics |
|------------------|-------------------------|--------------------------|
| Sapropelinite    | 20% ~60% (avg. 38.5%)   | Obviously, sapropelinite is developed with a lot of organic matter pores |
| Vitrinite        | 0% ~22% (avg. 6.3%)     | Commonly, vitrinite has no development of pores, but there are few pores or nanoscale dense pores |
| Inertinite       | 0% ~15% (avg. 5.2%)     | Inertinite usually develops no pores or develop stripped pores |
| Exinite (Low content and low pore-forming efficiency) | All recognized exinites have no development of pores |

Figure 8: Correlations between organic maceral content and organic surface porosity in X1 and X2 wells.
organic matters and sapropelinite content is relatively weak. The reasons are as follows: different samples have different vertical and plane positions, are affected by different external forces such as compaction, have different maturities of organic matter, and have different mineral contents [67, 68].

Organic surface porosity is basically positively correlated with sapropelinite content, but it shows weak correlations or weak negative correlations with exinite, vitrinite, and inerinite. Cao et al. believed that organic macerals in shale are one of factors which influence the development of organic matter pores. They pointed out that sapropelinite was a beneficial component for the development of pores, and it was the easiest to form pores. Inerinite hardly produced and discharged hydrocarbons in the process of thermal evolution, thus resulting in the formation and development of few pores [13]. Long et al. studied the Longmaxi Formation in Yueyu-1 well and concluded that vitrinite was easy to rupture by producing local abnormal pressure in the evolution process. As a result, a lot of micropores and small holes could be developed inside vitrinite and the spaces between vitrinite and minerals [69]. This is basically in accordance with research conclusions in this study. Song et al. identified the macerals in the same layer at edges of study area and found that sapropelinite was the major organic matter type in marine shale of the Longmaxi Formation, which accounted for 74.0% - 94.0% of total organic matters (avg. 82.2%). Moreover, there are extensive developments of organic matter pores [70]. This is consistent with research conclusions of the present study.

In this study, the in situ quantitative relationship between organic macerals and organic surface porosity was gained. Pore-forming efficiency of macerals controls the organic surface porosity, while the organic surface porosity restricts the organic porosity. The organic porosity also plays an important role in the shale pore system that determines storage, adsorption, and migration ability of gases. Hence, pore-forming efficiency is an essential parameter in the fine evaluation of organic-rich shale reservoir.

6. Conclusions

(1) Based on a qualitative and quantitative analysis of PFEDOM with SEM, it is concluded that the pore-forming efficiency of sapropelinite is the highest (avg. 38.5%), and the pore-forming efficiency of vitrinite, inerinite, and exinite is lower in the over-mature marine shale reservoir.

(2) A quantitative statistics on relative organic maceral contents is conducted by using the MAPS technology. It finds that in the studying section, the mean sapropelinite content is the highest (avg. 82.4%). Contents of vitrinite, inerinite, and exinite are relatively lower than 10%. Moreover, there are great differences among different layers. The relative content of sapropelinite along vertical direction of single well is higher at Long1,1 and Long1,3, but lower at Long1,2 and Long1,4. This law is mainly controlled by sea surface rising and falling in the period.

(3) In the studying section, organic surface porosity is relatively higher at Long1,1 and Long1,3, but lower at Long1,2 and Long1,4. Interlayer differences of organic surface porosity are consistent with that of sapropelinite, and there is a strong positive correlation between organic surface porosity and sapropelinite content. Contents of different organic macerals control the organic surface porosity which restricts the organic porosity. The total pores in organic matter are the main body of shale reservoir space. Hence, pore-forming efficiency is one of important constraints against performances of shale reservoirs which are rich of organic matters.

Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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