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Geological Characteristics of Shale Reservoir of Pingdiquan Formation in Huoshaoshan Area, Junggar Basin

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Abstract: Unconventional oil and gas, represented by shale gas and shale oil, have occupied an important position in global energy. The rapid growth of shale gas and shale oil production shows great potential for the exploration and development of shale resources. Junggar basin, the main oil-bearing basin in China, is rich in oil and gas resources, so it is of great practical significance to carry out systematic research on the geological characteristics of shale reservoirs in this region. To this end, this paper designates the shale reservoir of Pingdiquan Formation in Huoshaoshan area of the Jungar Basin as the research object, carries out a geological survey in that area, analyzes reservoir forming conditions using the geological interpretation method, analyzes different local trap reservoir types and their main control factors by dissecting the explored reservoir, optimizes and evaluates favorable traps using the source, fault, facies and circle coupling analysis method, establishes single good identification standard of sedimentary microfacies, and carries out well-connected sedimentary microfacies analysis. Using geochemical methods, such as rock pyrolysis, maceral analysis, vitrinite reflectance, kerogen carbon isotope, saturated hydrocarbon chromatography, etc., the abundance and types of organic matter of shale in different intervals are analyzed and the geological characteristics of shale reservoirs are evaluated. This paper aims to analyze the oil and gas content of the shale reservoir in Pingdiquan Formation in the Junggar Basin to provide reliable reservoir evaluation and guide better development of shale oil and gas resources in the future. The innovative expenditure of this paper lies in conducting the research from two aspects: the analysis of the main controlling factors of reservoir formation from the structural point of view and the analysis of the pore structure and geochemical characteristics of shale from the core experiment point of view, and also the classification of organic matter, so as to provide a basis for finding favorable traps. The results show that the shale sedimentary system in the study area is a small fluvial delta, which belongs to a compression structure, with developed NNE-oriented structural belts and faults; the structural form is a short-axis anticline as a whole, forming a structural coil closure at −900 m, with a trap area of 50 km^2 and a closure height of 180 m. According to the geological interpretation method, 19 faults of all levels were found in the area and the vertical migration conditions of oil and gas were good. Pingdiquan Formation was oil-bearing, with many vertical oil-bearing strata and strong horizontal independence of the reservoir. The sedimentary thickness of the Permian Pingdiquan Formation in the study area is 300~1200 m and the oil-bearing strata are divided into 3 oil-bearing formations, 9 sublayers, and 22 monolayers from top to bottom. The abundance of organic matter in different strata is generally high, with an average total organic carbon content of 3.53%, an average hydrocarbon generation potential of 18.1 mg/g, an average chloroform asphalt content of 0.57%, and an average total hydrocarbon content of 3011 μg/g, all of which belong to the shale standard, especially Ping-2. The organic matter in different layers belongs to types I-II1, and the organic matter types are I-II1, I-II2, and II1-II2, respectively. The average carbon isotope of shale kerogen is −2.4%, which belongs to type II2 kerogen.

Keywords: Junggar basin; Huoshaoshan block; shale reservoir; geological characteristics

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1. Introduction

With large-scale growth of oil and gas exploration, shale oil and gas development has occupied an important position in the global energy structure and is being replicated and promoted continuously worldwide. The shale oil and gas production industry has grown rapidly, showing great exploration and development potential. China is rich in shale oil and gas resources, which are mainly distributed in Songliao, Ordos, Junggar, Bohai Bay and other basins. Among them, the exploration of shale oil and gas in the Junggar Basin has made remarkable progress, and shale is widely developed in this basin. The Junggar basin is rich in oil and gas resources, but the distribution these resources is extremely uneven. The oil and gas reserves in the northwest and the belly of the basin account for more than 70%, but they account for only less than 5% in the southeast [1]. With the advancement of geological investigations, a rich shale reservoir has been found in the southeast of Junggar Basin, which has certain potential for oil and gas resources development. Therefore, it is of great practical significance to extensively study the geological characteristics of shale reservoirs in this region.

A great deal of research has been conducted on the geological characteristics of shale reservoirs and some achievements have been made. Li Junfeng, Z. et al. (2016, 2019, 2010) studied the lithology and lithofacies characteristics of shale in Pingdiquan Formation, Huoshaoshan Area, Junggar Basin, divided the types of shale sedimentary facies, determined the favorable combination of reservoirs through shale space–time evaluation, and studied the characteristics and controlling factors of shale reservoirs using rock slice and scanning electron microscope [2–4]. It was concluded that the shale reservoirs in the study area mainly developed secondary pores, intergranular dissolved pores, intergranular pores and fractures, which belonged to low porosity and low permeability reservoirs. Caineng, Z. et al. (2013) used vitrinite reflectance and peak temperature of rock pyrolysis as two of the parameters and regarded the maturity of organic matter as the judgment index of organic matter entering the oil–gas generation stage [5]. At the same time, with the increase in shale thermal evolution, the hydrocarbon generation of organic matter increases. When the hydrocarbon generation threshold exceeds 1.0%, its rate of organic matter obviously accelerates, the gas production increases rapidly, and the pore number, porosity, pore-specific surface area, and reservoir space of shale all show an increasing trend [6–8]. Wang, Y. et al. (2021, 2016, 2019) researched shale mineral composition and found that shale is mainly composed of minerals, such as quartz, feldspar, calcite, clay, etc., among which quartz and clay have the maximum content; shale also contains some organic matter [9–11]. At the same time, it has been found that shale clay minerals are mainly montmorillonite and kaolinite. Guo, T. L. (2016) have identified, using advanced technology, the types of quartz in shale, which mainly includes terrigenous clastic, biogenic, and clay mineral transformation [12]. Meanwhile, the biogenic quartz is positively correlated with the organic carbon content of shale, which plays a positive role in fracturing shale reservoirs. Zou, C. N. et al. (2015, 2021) have carried out the analysis of shale mineral components using microscope, infrared spectroscopy, X-ray diffraction analysis, energy dispersive X-ray spectroscopy and other techniques, and concluded that the formation and evolution of pores in shale is the key factor determining shale oil and gas accumulation, and it is also related to geological sedimentation and diagenesis [13–15]. Dong, D. et al. (2018) carried out quantitative analysis of the micro-scale shale physical properties using electron microscope, scanning electron microscope, and X-ray diffraction energy spectrometer, and through data image processing software quantitatively analyzed the mineral composition, grain size, and morphology of shale, and combined the quantitative analysis results of the shale minerals using the large-scale backscattering image stitching technology to realize the micro-scale pore and mineral composition characterization of the core [16]. Li, J., Li, H., Yang, C., Wu, Y., Gao, Z., Jiang, S. (2022) put forward that the physical properties of shale reservoirs are characterized by porosity, pore volume, specific surface area, and permeability [17]. At the same time, the number of shale pores is mainly related to the abundance and maturity of organic matter, and the types and contents of clay minerals. Through the analysis of the geological characteristics of the Longmaxi Formation shale reservoirs, the interaction between the abundance of organic matter and shale porosity is obtained. As the organic matter content of shale increases gradually, its porosity shows a form of rapid increase-slow decrease-rapid increase-rapid decrease [18–20]. Hou, Z. K. et al. (2019) have studied shale porosity in southern Sichuan and found that organic carbonation affects organic porosity. When Ro < 3.6%, organic porosity increases continuously, and when Ro ≥ 3.6%, organic porosity decreases continuously [21]. At the same time, TOC content controls the gas content of the shale reservoir, and clay mineral adsorption helps to enhance the gas capacity of the reservoir [22].

Junggar basin, the main oil-bearing basin in China, is rich in oil and gas resources, so it is of great practical significance to carry out systematic research on the geological characteristics of the shale reservoirs in this region [23]. In this paper, the shale reservoir of Pingdiquan Formation in the Huoshaoshan Area, Junggar Basin is taken as the research object. The geological interpretation method is used to analyze the reservoir forming conditions, different local trap reservoir types, and their main control factors; the coupling analysis method of source, fault, facies, and circle is used to optimize the favorable traps; and the sedimentary microfacies analysis of well connection is carried out. Geochemical methods, such as rock pyrolysis and maceral analysis, are used to analyze the organic matter abundance and types of shale in different sections, providing theoretical data support for oil and gas exploration and development of shale reservoirs.

2. Materials and Methods

(1) Geological background

The shale reservoir of Pingdiquan Formation in the Huoshaoshan Area of Junggar Basin is located at the southern foot of Kelamei Mountain in Jimsar County, close to National Highway 216, with convenient transportation, about 190 km away from Urumqi. The climate in the study area is hot and dry in summers and cold in winters. The annual temperature varies greatly from 40 °C to −42 °C; the annual rainfall is less than 200 mm and there is no surface water system. The terrain of the study area is high in the northeast and low in the southwest, accompanied by some hills. The middle part is relatively flat, with an altitude of 580~650 m and an average sea wave of 620 mm.

The shale sedimentary system in the study area is a small river delta with multiple positive cycles. Through multi-well fine calibration, the characteristics of each sequence filling group and the reflection characteristics of the sequence interface are carried out, and the corresponding relationship between sequence change characteristics and reservoir rock mass is analyzed. On the whole, the structural form of the study area is a short-axis anticline, with a long axis of 15 km and a short axis of 7 km. At −900 m, a structural coil closure is formed, with a trap area of 50 km^2 and a closure height of 180 m. The structure of the region has experienced many stages of the tectonic movement of Permian sedimentation, the active period of Triassic tectonic movement, and the influence of the Indosinian movement at the end of Triassic. Its structural form is compression, resulting in a series of NNE tectonic belts and faults. At the same time, under the control of thrust stress, small NW shear compression–torsion faults developed in the thrust stage of the whole region.

(2) Forming conditions of shale reservoir

The study area is structurally located in the anticline of the Shazhang fault-fold belt in the eastern uplift of the Junggar Basin and its structural position is very favorable for gas reservoirs. The sedimentary environment belongs to the front of the shallow lake delta and particularly the delta front subfacies, mainly developing east–west provenance and shale bodies. Through geological exploration, it is revealed that there are many sets of reservoir–cap assemblages and oil layers in the Pingdiquan Formation. In the shale oil and gas development zone, reverse faults are developed in the target bed of Permian, the scale of which is relatively large, and normal faults are developed locally. Using the geological interpretation method, 19 faults of various levels were found in the area and the vertical migration conditions of oil and gas were good [24]. The geographical location and geological structure characteristics of the study area are shown in Figure 1.

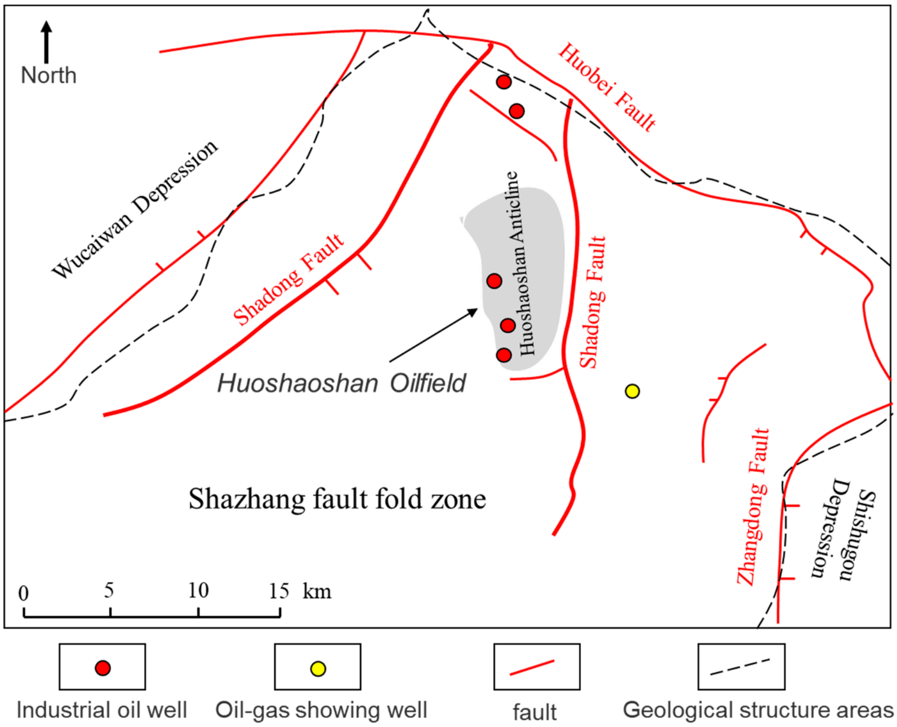

Figure 1. Geographical location and structural sketch of Huoshaoshan oilfield (after Chen, 2016) [25].

In the study area, the upper lenticular shale in the shale reservoir is distributed in a small range, most of which are unconnected, and the single rock layer is thin. The reservoir is divided into four layers of which the upper three layers are shale and belong to the reservoir development layer, and the fractures in the bottom rock are stable and well connected. Through fine calibration of reservoirs, reflection characteristics and petrophysical analysis of reservoirs with different thicknesses are carried out.

The common types of reservoirs are structural, stratigraphic and lithologic, and the controlled factors of oil and gas distribution and migration are different in different types of reservoirs. According to the existing research results, the shale reservoirs in the study area are mainly structural reservoirs. The study area is dominated by structural reservoir control. Through the analysis of the geological characteristics of the wing of the main anticline of the oilfield via several exploration wells, it is concluded that the periphery of the oilfield has great lithologic reservoir-forming potential. By dissecting the explored reservoirs in the oilfield, and analyzing different local trap reservoir types and their main controlling factors, the controlling factors of effective accumulation and accumulation of fault lithology are obtained. By using the coupling of source, fault, facies, and circle, the hydrocarbon accumulation law is analyzed and the favorable traps are optimally evaluated [26].

Shale gas reservoirs in the study area are unconventional and the controlling factor of reservoir formation is lithologic reservoir formation. At present, many shale gas wells have been drilled in the study area. The drilling results in the study area show that wells H231 and H234 have obtained industrial oil flow in shale section, and wells 2-H231 and Huo 2-H220 in Shadong 2 block have obtained industrial oil flow. The gas reservoir profiles of the above four wells are representative and the detailed description is as follows.

Wells H231-H234 in the reserve periphery of the west wing of the anticline and many wells in the east wing of Shadong 2 fault nose in the study area obtained industrial oil flow in H1-H3 and the depth of some shale beds exceeded −1042 m, which indicated that the reservoir group was not controlled by H4 oil–water interface and belonged to lithologic reservoir control the in structural background. Through the analysis of the reservoir profiles of Shadong 2-H231-Huo2-H220 wells, it is concluded that Pingdiquan Formation is oil-bearing, with many vertical oil-bearing strata and strong horizontal independence of the reservoir. In addition to the main proven area, oil and gas are also found in the slope area wells and the lithologic control characteristics are obvious.

(3) Experimental equipment and materials

Materials: The core samples in the test and analysis are all from the cores obtained from the drilling of the Permian Pingdiquan Formation in the study area. Dyed resin or liquid glue needs to be injected into the pores under vacuum before the cast sheet is ground into thin sheets. The common casting bodies are mainly red casting bodies and blue casting bodies, and the red casting body is adopted in this experiment. The prepared casting sheet is placed on an optical microscope to observe the characteristics of minerals, pore structure and so on and the images are collected. Firstly, the image is preprocessed, which includes two steps: image enhancement and image filtering. Secondly, the image is segmented and the pores are extracted. Finally, on the basis of image processing, the counting statistics method is combined with the topological method, and the fractal characterization of pore structure is performed according to the thin slice data. According to the experimental method, the core slice to be measured is carried out. During the slice-making king process, the representative rock samples are selected first, and the samples are washed with oil. During the making process, the vacuum state should be maintained and the prepared casting slice is cut and numbered. After rough grinding, fine grinding, and finish grinding, the thickness of the casting slice is 0.03 mm, and the label is attached for identification and use. Shale core samples are shown in Figure 2.

Figure 2. Core samples of the Permian Pingdiquan Formation in the study area.

Instruments: RockEval 7 rock pyrolyzer, carbon isotope analyzer, ZHM-1B grinding machine (ZHM-2), press machine (ZHY-505), rock pore casting instrument (JS-5), full-diameter core permeability tester (DYX-1), cathode emission electron microscope (CL8200 MK5), rock cutting machine (DQ1-6), a fully automatic measuring instrument for specific surface area and pore size distribution (MiniX-1), Zeiss Primotech polarizing microscope, core holder, etc. Auxiliary materials include emery, epoxy resin, curing agent, dyeing agent, fir gum, etc.

3. Results

(1) Stratigraphic characteristics

The shale reservoir basement in the study area is mainly Carboniferous intermediate-basic igneous rock and the sedimentary strata are Permian, Triassic, Jurassic, Cretaceous, and Tertiary. Permian is the most important oil-bearing layer in the study area, which is characterized by complete positive cycle deposition and multiple first-order small cycles. The distribution of Triassic is very uneven, with the Xiaoquangou group distributed in the south of the research area, which was completely denuded in the east block of Shandong.

Jurassic strata are widely distributed throughout the study area. Cretaceous can be seen in the Tugulu group, mainly distributed in the south of the study area but missing in the north. Tertiary strata are mainly distributed sporadically in the south of the study area. The quaternary system is undeveloped.

The Permian Pingdiquan Formation, the target layer of the shale reservoir in the study area, has a sedimentary thickness of 300~1200 m, and it is composed of members Ping-1, Ping-2, and Ping-3 from bottom to top; according to the sedimentary cycle, lithology, electrical property, formation thickness and oil-bearing characteristics of Pingdiquan Formation in the study area, it can be divided into three sub-sections from bottom to top, namely, Pingyi member, Pinger member and Ping-3 member. Among them, the Ping member is mainly composed of gray argillaceous siltstone and gray-black cloudy mudstone, gray siltstone, gray fine sandstone and sand and mudstone interbedded; Pinger 2 member is dominated by micrite dolomite, mudstone and siltstone; and the upper Pingsan member is interbedded with thick layers of red, light gray, gray mudstone, sandy mudstone and argillaceous dolomite, with light gray siltstone and fine sandstone locally. Because of fine grain size and undeveloped gaps, it is a regional cap rock in the study area, creating favorable geological conditions for oil and gas formation, and this oil-bearing stratum is called the Huoshaoshan oil-bearing strata. According to the sedimentary cycle and lithologic characteristics, the oil-bearing strata are divided into 3 oil-bearing strata, 9 sublayers, and 22 monolayers from top to bottom (Table 1).

Table 1. Stratigraphic division of Permian Pingdiquan Formation in the study area.

System	Group	Shale Formation	Sublayer	Monolayer
Permian	Pingdiquan	H_1 (Ping-1)	H_1^1	$H_1^{1\text{-}1}$ $H_1^{1\text{-}2}$
			H_1^2	$H_1^{2\text{-}1}$ $H_1^{2\text{-}2}$ $H_1^{2\text{-}3}$
			H_1^3	$H_1^{3\text{-}1}$ $H_1^{3\text{-}2}$
		H_2 (Ping-2)	H_2^1	$H_2^{1\text{-}1}$ $H_2^{1\text{-}2}$ $H_2^{1\text{-}3}$
			H_2^2	$H_2^{2\text{-}1}$ $H_2^{2\text{-}2}$ $H_2^{2\text{-}3}$
			H_2^3	$H_2^{3\text{-}1}$ $H_2^{3\text{-}2}$ $H_2^{3\text{-}3}$
		H_3 (Ping-3)	H_3^1	$H_3^{1\text{-}1}$ $H_3^{1\text{-}2}$ $H_3^{1\text{-}3}$
			H_3^2	$H_3^{2\text{-}1}$ $H_3^{2\text{-}2}$
			H_3^3	H_3^3

The oil-bearing strata of the Permian Pingdiquan Formation reservoir in the study area belong to the lake–fan delta sedimentary system, and H_1–H_3 deposits are mainly delta front, with complex sublayer deposits and great microfacies changes. The provenance mainly comes from the northeast and there is another secondary provenance from the northwest. According to the analysis of the characteristics of rock electricity, sedimentary structure, the thickness of single layer, grain size, and debris content, it can be divided into microfacies, such as underwater distributary channel, inter-channel bay deposit, delta front sheet sand deposit, shore shallow lake and sand bar deposit, among which underwater distributary channel and front sheet sand are favorable reservoir types in this area.

According to the data of core and rock electricity, the single-well identification standard of sedimentary microfacies is established, and the analysis of sedimentary microfacies of connecting wells is carried out. Based on single-well sedimentary facies analysis, the phase sequence relationship between adjacent wells is established using electrical logging data, and the distribution characteristics of sedimentary facies in two-dimensional space are determined. By studying the structural position and geological evolution law of shale reservoir, starting from exploration and development, two well-connecting profiles reflecting sedimentary facies in this area are established, one of which is near the east–west and the other is in the northwest. In the direction of provenance, this section is nearly east–west, passing through wells Huoxi 3, Huoxi 2, Huoxi 16, and Huo 5 in turn from west to east, which is similar to the direction of provenance, showing the lateral variation characteristics of sedimentation along the provenance. In this section, the longitudinal sequence is lake regression from bottom to top and it transits from shore-shallow lake to braided river delta front. The lateral facies belt changes rapidly and the characteristics of H_1 formation are the most obvious. A single channel is narrow and the plane extension range is small. After the vertical superposition of multiple channels, the plane features are relatively stable and the horizontal continuity gradually decreases. In the direction of the cutting source, this section is northwest–southeast, passing through five wells of Huoxi 4-Huoxi 2-Huoxi 17-Huo 9-Huo 21, and the section line is basically on the outside or edge of the reserve area, which well reflects the sedimentary characteristics of cutting source defense line and the sedimentary model of the reserve area boundary and is conducive to guiding the reserve area expansion and deployment. In this section, the vertical, horizontal, and near-EW profiles are similar, and the microfacies continuity of the distributary channel is poor, and it quickly pinches out after one well spacing. All H_3~H_1 develop shallow lacustrine microfacies, which are the extension ends of distributary channels.

Plane distribution of sedimentary microfacies is the key step in reservoir heterogeneity and maintaining oil distribution, and it is also an important geological basis for development analysis. Based on the analysis of the regional sedimentary background, the plane distribution of sedimentary microfacies of the target layer in the study area is analyzed, and it is concluded that the shale of Pingdiquan Formation in the study area mainly develops delta front deposits, which is characterized by strong river action. From H_3~H_1 sedimentary microfacies, it can be seen that there are two provenances in northeast and northwest in the study area, and the northeast provenance of each layer is widely distributed in the plane with the main provenance, while the northwest provenance is relatively limited. The lake area of H_3 is the largest, and the area of the upper layers of lake water gradually decreases, showing the characteristics of the lake retrogression sequence. The sedimentation period of H_1 has the strongest hydrodynamic force, with the longest river channel extending to the lake and the largest delta plane distribution. The width of a single channel is between 300 and 600 m; multiple channels are stacked and developed, and the plane distribution of multiple channels is relatively wide, with a width of 600~2000 m.

The H_3 stratum in the study area is widely developed, with stable lateral thickness, and has the potential for large-scale exploration. The reservoir conditions in the Huoshaoshan anticline and Huodong syncline are good. Conducting a nearly east–west profile across the Huoshaoshan anticline shows that the H_3 stratum develops stably in east–west direction and has a relatively coordinated thickness, passing through Wucaiwan depression, Shaqiu River uplift, Huoshaoshan anticline, and Huodong syncline. Through fine calibration and structural interpretation, it can be concluded that the H_3 stratum has developed all structural zones and its thickness changes with structural location and geomorphic characteristics, but it is stable as a whole. By comparing the north–south and east–west sections, it is concluded that the H_3 plane of the Pingdiquan Formation in Huoshaoshan Block is widely distributed and has large-scale exploration potential.

The study area has a deep lake–semi-deep lake deposit, which is multi-source and contains mainly chemical deposition. The lithology is complex, mainly composed of dolomitic shale and dolomitic mudstone, accompanied by various clastic rocks and carbonate rocks. To guide the development and deployment, the statistics of oil-bearing properties of various lithologies are carried out. Dolomite mudstone has a large core base, but the oil-bearing level is low, while dolomitic shale is generally full of oil, which has the greatest potential for exploration and development. Through observing the drilled cores and cast thin sections of Pingdiquan Formation H_3, it is concluded that the pore types in the rock body include intergranular voids, dissolved holes, fractures, bedding planes, etc. Combined with the coring data, logging, nuclear magnetic resonance, and rapid saturation analysis results, Pingdiquan Formation H_3 contains two types of dessert layers: Class I dessert layer is mainly a reservoir with intergranular pores of thick shale (including dolomitic shale), and its logging curves are characterized by medium-high GR and medium-low resistivity. Class II dessert layer is thin mudstone, which cannot be identified via conventional logging. The whole reservoir is characterized by medium and high-resistance interbeds and FMI shows massive bright and dark stripes. This dessert combination is distributed in the middle of $H_3{}^1$ and the upper part of $H_3{}^2$.

(2) Characteristics of rock mass in the study area

The statistical results of pore structure parameters show that the pore morphology in the study area is relatively regular as a whole. There is a good negative correlation between pore shape factor and pore aspect ratio, and the square of correlation coefficient is above 0.78. When the pore shape factor increases, the aspect ratio decreases, that is, the closer the pore shape is to a circle, the closer the diameter ratio of its long axis and short axis is to 1. There is a good negative correlation between pore equivalent diameter and pore specific surface, and the square of correlation coefficient is above 0.88. When the pore equivalent diameter increases, the specific surface decreases, that is, the larger the pore, the smaller the specific surface.

The shale in the study area is mainly characterized by multi-source mixing, transitional lithology, scattered dessert, and intra-source accumulation, and belongs to the squeezed foreland saline lake basin shale oil. The industrial oil flow was produced in the No. 25 well, and a series of high-yield industrial oil flow wells were found in the subsequent exploration and development, which greatly promoted the exploration progress of shale oil in the Junggar basin. A variety of rock types are developed in the study area, mainly including conglomerate, sandstone, siltstone, mudstone, shale, and limestone, among which shale is the most widely developed. Table 2 shows the characteristics of shale bodies in the study area. In this paper, 30 rock samples, 10 in each horizon, are analyzed and the parameters of each horizon used in this paper are the average values of all the samples in this horizon.

Table 2. Characteristics of shale bodies in the study area.

Lithology	Porosity (%)	Permeability (μm^2)	Deposition Thickness (m)
Shale	3~13	$(0.05\sim0.7) \times 10^{-3}$	40 m

In this paper, the organic matter abundance parameters of shale samples from 15 exploration wells in the study area are statistically analyzed. Table 3 and Figure 3 show the organic matter abundance of shale in the study area. The abundance of organic matter mainly includes shale's total organic carbon content, hydrocarbon generation potential, chloroform asphalt content, and total hydrocarbon content. It can be seen from Table 3 that the abundance of organic matter in different strata in the study area is generally high, with an average total organic carbon content of 3.53%, an average hydrocarbon generation potential of 18.1 mg/g, an average chloroform asphalt content of 0.57% and the average total hydrocarbon content of 3011 μg/g. All three strata belong to the standard of good shale, especially the Pinger formation, which has a very strong hydrocarbon generation capacity.

Table 3. The abundance of shale organic matter in the study area.

Position	Total Organic Carbon Content (%)	Hydrocarbon Generation Potential (mg/g)	Content of Chloroform (%)	Total Hydrocarbon Content (μg/g)	Type
Ping-1	2.5	6.8	0.58	2832	Good-high quality
Ping-2	5.3	31.3	0.77	4212	High quality
Ping-3	2.8	16.2	0.36	1990	Good- high quality

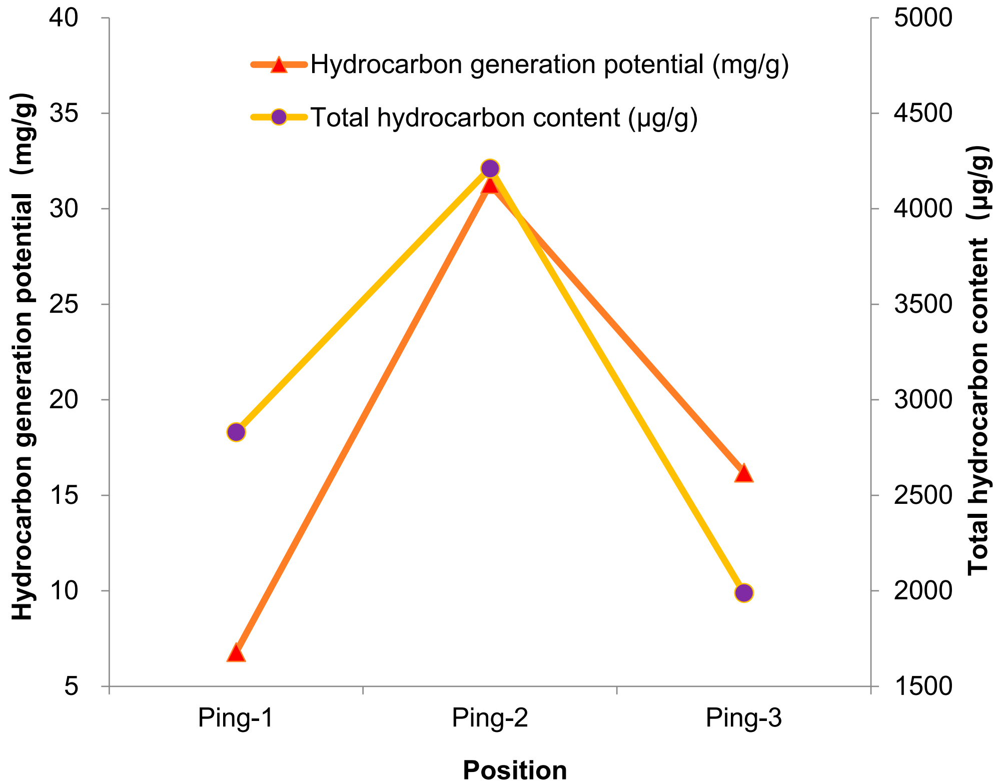

Figure 3. Abundance parameters of shale organic matter in the study area.

The type of medium shale organic matter directly determines the quality of shale oil and gas reservoirs. Through the analysis of saturated hydrocarbon components, kerogen macerals, root carbon isotopes, and pyrolysis parameters of shale reservoirs in the study area, the types of organic matter were studied. Table 4 shows the overall types of shale organic matter in the study area and Table 5 shows the types of shale organic matter in the study area. Through the experimental study, it is concluded that the hydrogen index of Ping-1 shale is in the range of 85~810 mg/g; saturated hydrocarbon is in the range of 49~58%; aromatic hydrocarbon is in the range of 8~19%; and non-hydrocarbon + asphaltene is in the range of 21~53%. On the whole, the organic matter belongs to type I-II_1 and the maceral content of kerogen is in the range of 42~86%. The vitrinite content ranges from 5% to 18%, indicating that its organic matter type belongs to type I-II_1. The hydrogen index of shale in the Ping-2 is in the range of 145~766 mg/g; saturated hydrocarbon is in the range of 22~77%; aromatic hydrocarbon is in the range of 1~27%; and nonhydrocarbon +asphaltene is in the range of 14~52%. Therefore, the overall type of organic matter belongs to type I-II_1. At the same time, the chitin content of kerogen macerals ranges from 5% to 59% and the vitrinite content ranges from 11% to 52%, indicating that the organic matter type of kerogen belongs to type I-II_2. The hydrogen index of shale in the Ping-3 is 283~605 mg/g; saturated hydrocarbon is 18~73%; aromatic hydrocarbon is 14~29%, and nonhydrocarbon +asphaltene is 12~60%. Therefore, the overall type of organic matter belongs to type I-II_1. At the same time, the chitin content of kerogen macerals ranges from 5% to 48% and the vitrinite content ranges from 5% to 273%, indicating that the organic matter type of kerogen belongs to type II_1-II_2.

Table 4. Overall types of shale organic matter in the study area.

Position	The Average Value of Hydrogen Index (mg/g)	Average Saturated Hydrocarbon (%)	Average Aromatic Hydrocarbon (%)	Average Value of Non-Hydrocarbon + Asphaltene (%)	Total Organic Matter Type
Ping-1	380	52	16	35	I-II_1
Ping-2	421	47	18	36	I-II_1
Ping-3	477	52	19	32	I-II_1

Table 5. Types of shale organic matter in the study area.

Position	The Average Content of Kerogen Macerals and Crusts (%)	Average Vitrinite Content (%)	Organic Matter Type
Ping-1	67	10	I-II_1
Ping-2	33	22	I-II_2
Ping-3	32	14	II_1-II_2

Figure 4 shows the overall evaluation index of shale organic matter types in the study area and Figure 5 shows the evaluation index of shale organic matter types in the study area. During the evolution of shale in the study area, the carbon isotope composition of kerogen has no obvious change, indicating that it has a good index of organic matter types. The carbon isotope composition of type I kerogen of aquatic algae is light, while that of type III kerogen of terrestrial higher plants is heavy. On the whole, the carbon isotope values of kerogen of Pingdiquan Formation shale in the study area range from −2.9% to −2.2%, with an average of −2.4%, which belongs to type II_1 kerogen.

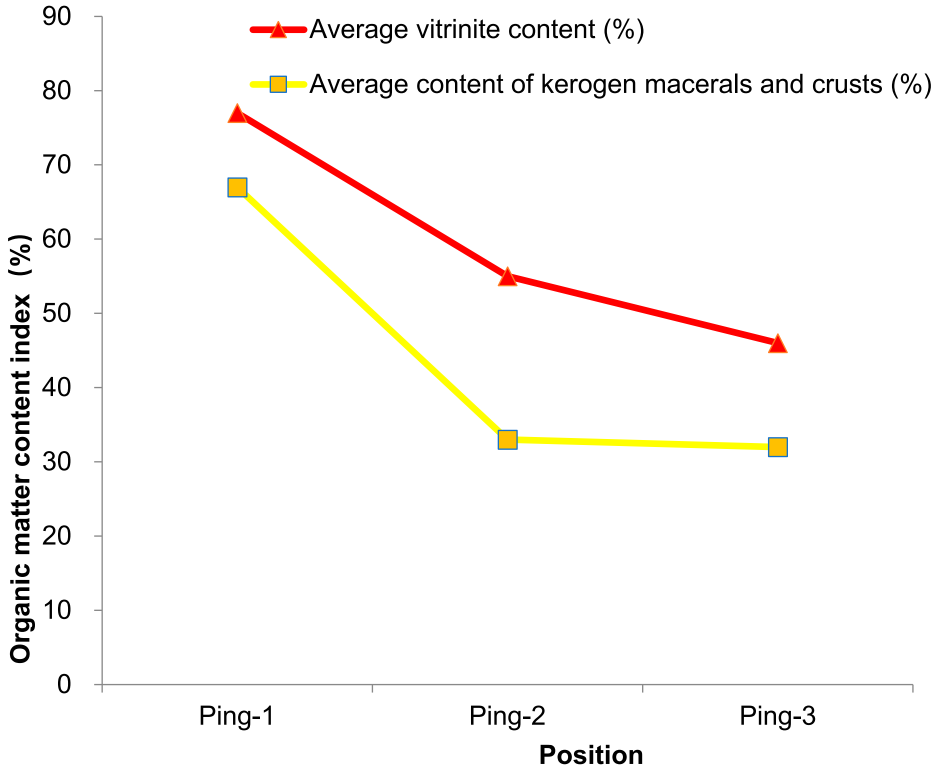

Figure 4. Evaluation index of shale organic matter types in the study area.

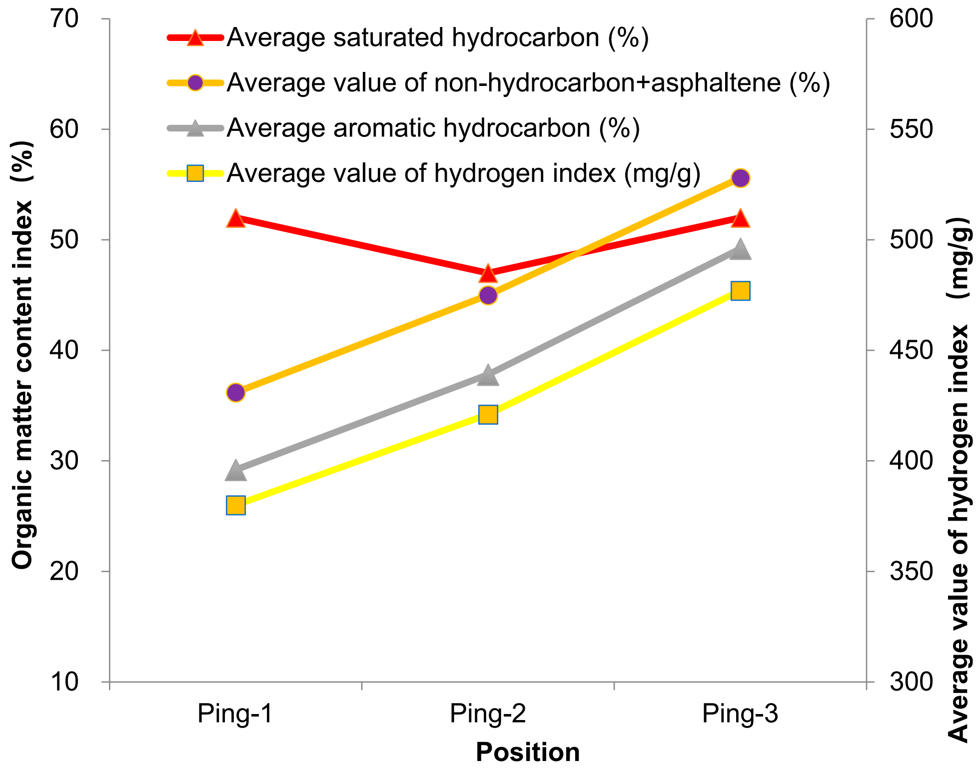

Figure 5. Evaluation index of overall types of shale organic matter in the study area.

4. Conclusions

Junggar basin is the main oil-bearing basin in China, with abundant oil and gas resources. It is of great practical significance to carry out systematic research on the geological characteristics of shale reservoirs. In this paper, considering the shale reservoir of Pingdiquan Formation in the Huoshaoshan Area of the Junggar Basin as the research object, geological survey and geological interpretation are carried out to analyze the reservoir-forming conditions of the shale reservoir in the research area. The coupling analysis method of source, fault, facies, and circle is used to analyze different local trap reservoir types, and their main control factors and favorable traps are optimally evaluated. Various geochemical methods are used to evaluate the organic matter abundance and types of shale in different sections, providing theoretical data support for oil and gas exploration and development of shale reservoirs. The main research results are as follows:

(1) The shale sedimentary system in the study area is a small river delta with multiple positive cycles of sedimentary rhythms. The structure in the study area is compressed, with development of NNE structural belts and faults. The structural form is a short-axis anticline, with a long axis of 15 km and a short axis of 7 km; a structural coil closure is formed at −900 m, with a trap area of 50 km^2 and a closure height of 180 m. According to the geological interpretation method, there are 19 faults at all levels found in the area and the vertical migration conditions of oil and gas are good. Through the analysis of the reservoir profile of well Dashadong 2-H231-Huo2-H220, it is found that Pingdiquan Formation is oil-bearing, with many vertical oil-bearing strata and strong horizontal independence of the reservoir.

(2) The shale sedimentary strata in the study area are Permian, Triassic, Jurassic, Cretaceous, and Tertiary. The Permian Pingdiquan Formation of the target formation has a sedimentary thickness of 300~1200 m, which is divided into Ping-1, Ping-2, and Ping-3 members from bottom to top. According to the sedimentary cycle and lithologic characteristics, the oil-bearing strata are divided into 3 oil-bearing formations, 9 sublayers, and 22 monolayers from top to bottom. There are two provenances in the northeast and northwest in the study area, and the northeast provenance of each layer

is widely distributed in the plane, which is the main provenance. There are various structural belts in H_3 formation, whose thickness varies with the structural position and geomorphological features, but it is stable as a whole and has the potential for large-scale exploration. The abundance of organic matter in different strata in the study area is generally high, with an average total organic carbon content of 3.53%, an average hydrocarbon generation potential of 18.1 mg/g, an average chloroform asphalt content of 0.57%, and an average total hydrocarbon content of 3011 μg/g. All three strata belong to the standard of good shale, especially the Pinger Formation, which has a very strong hydrocarbon generation capacity. Organic matter types in different strata in the study area belong to type I-II_1, and the organic matter types are I-II_1, I-$II_{2,}$ and II_1-II_2, respectively. During the evolution of shale, the carbon isotope composition of kerogen is not obvious. The carbon isotope composition of type I kerogen of aquatic algae is light, while that of type III kerogen of terrestrial higher plants is heavy. On the whole, the carbon isotope value of the shale kerogen of Pingdiquan Formation in the study area is −2.9~−2.2%, with an average value of −2.4%, belonging to type II_1 kerogen.

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