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The Basic Characteristics and Four-Relationship of the First Reservoir of the Sangonghe Formation in the Mosuowan Area

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Abstract

The Mosuowan area in the Junggar Basin is surrounded by oil source depressions and is characterized by abundant oil and gas resources. Based on a clear understanding of the reservoir's basic characteristics, an in-depth analysis of the reservoir's four relationships was conducted. The primary lithologies of the first section of the Sangonghe Formation reservoir include fine sandstone and medium-fine sandstone. Oil leaching is predominantly observed in medium-fine sandstone, whereas fluorescence is more common in fine sandstone. The average porosity and permeability are 10.2% and 2.18 mD, respectively, indicating the presence of low to ultra-low porosity and permeability reservoirs. Among the lithologies, unequal-grained sandstone exhibits the best physical properties, followed by medium-fine sandstone. The oil content shows a negative correlation with both acoustic wave travel time and resistivity. The reservoir characteristics indicate that coarser lithologic grain sizes generally correspond to better physical properties, and better physical properties are associated with higher oil content grades. Clarifying the four relationships of the reservoir enhances the scientific rigor and reliability of reservoir evaluation and provides fundamental theoretical support for the efficient development of oil and gas resources.

Keywords

Mosuowan Area, A Section of the Sangonghe Group, Reservoir Characteristics, Four-Sex Relationship

1. Introduction

The Mosuowan area is situated within the central depression of the Junggar Basin and is surrounded by hydrocarbon-generating depressions. It possesses a strategically advantageous geographical location, characterized by relatively low tectonic activity and significant burial depth. Due to its proximity to hydrocarbon sources, the region is abundant in oil and gas resources, making it a promising area for exploration (Sun et al., 2017; Zhang et al., 2023; Imin, 2021). Understanding the characteristics of reservoir lithology, physical properties, oil saturation, and electrical properties, as well as their interrelationships, is crucial for enhancing the efficiency of oil and gas exploration and development. Currently, research on the four-property relationships of the first section of the Sangonghe Formation is insufficiently systematic, resulting in limited technical support for optimizing exploration and development strategies in this reservoir (Ye et al., 2020). Based on core analysis, logging interpretation, laboratory testing, physical property data, and production testing, this study conducted microscopic observations and statistical analyses of rock thin sections and fluorescent thin sections. Additionally, advanced analytical techniques such as CT scanning and scanning electron microscopy were employed to investigate the characteristics of tight reservoirs in the first section of the Sangonghe Formation in the Mosuowan area. The fundamental characteristics and interrelationships of the four reservoir properties were systematically analyzed.

2. Method

A total of 61 reservoir samples were collected in this study, which were taken from different locations of the target reservoir to ensure a comprehensive reflection of the reservoir's characteristics. The depth interval range of the samples is 2362.63 - 6998.49 meters, with the depth interval set at 5 meters. Such a setting is conducive to a detailed analysis of the physical property changes of the reservoir at different depths. Porosity determination: A helium porosity meter (in accordance with SY/T 6383-2016 standard) was used, with a test pressure of 0.1MPa and an equilibrium time of ≥ 300 seconds. The sample specification is a cylinder with a diameter of 2.54 cm (1in) and a length ranging from 2.54 to 5.08cm. The surface is sanded with 600-mesh sandpaper to eliminate the influence of micro-cracks. Permeability determination: The pulse decay method (Appendix C of SY/T 6285-2011) was used. The test gas was nitrogen, with a confining pressure of 2MPa and a flow rate of 0.5 to 5.0 mL/min. Each sample was tested three times, and the arithmetic mean was taken, with a relative error of less than 5%.

3. Regional Geological Overview

The study area is the Mosuowan Uplift, a secondary structural unit in the central depression of the Junggar Basin (**Figure 1**). It is surrounded by hydrocarbon-rich depressions, with abundant oil and gas sources. The Mosuowan Uplift is a typical "concave within a convex" structure, featuring a superior geographical location and rich potential for oil and gas resources. This makes it an important area for oil and gas exploration and development, and a strategic target for deep-deep to ultra-deep oil and gas exploration within the basin. The protruding area of Mosuowan is approximately 2800 square kilometers, and the burial depth range is generally between 4000 and 6000 meters (Gao et al., 2017a, 2017b).

The Mosuowan Uplift is a long-inherited ancient uplift on the northwest margin of the Junggar Basin. Its evolution has gone through three stages: uplift during the Haixi period, subsidence and adjustment during the Indosin-Yanshanian period, and shaping during the Himalayan period. This uplift controls the thermal evolution of the surrounding source rocks, reservoir distribution and oil and gas transport and accumulation. It is an important target area for oil and gas exploration in the basin, especially the sand-body oil and gas reservoirs in the Jurassic Sangonghe Formation have the greatest potential (Zhou et al., 2005; Kuang et al., 2005). In the future, it is necessary to deepen the research on the matching relationship between fault activity periods and oil and gas accumulation periods.

The Sangonghe Formation (J1s) in the study area can be divided into three sections from bottom to top based on lithological characteristics: the first section of the Sangonghe Formation (J1s1), which is mainly composed of gray sandstone and mudstone; the second section of the Sangonghe Formation (J1s2), which is mainly composed of gravelly sandstone; and the third section of the Sangonghe Formation (J1s3), which is mainly composed of dark gray mudstone. The first section of the Sangonghe Formation in the study area as a whole

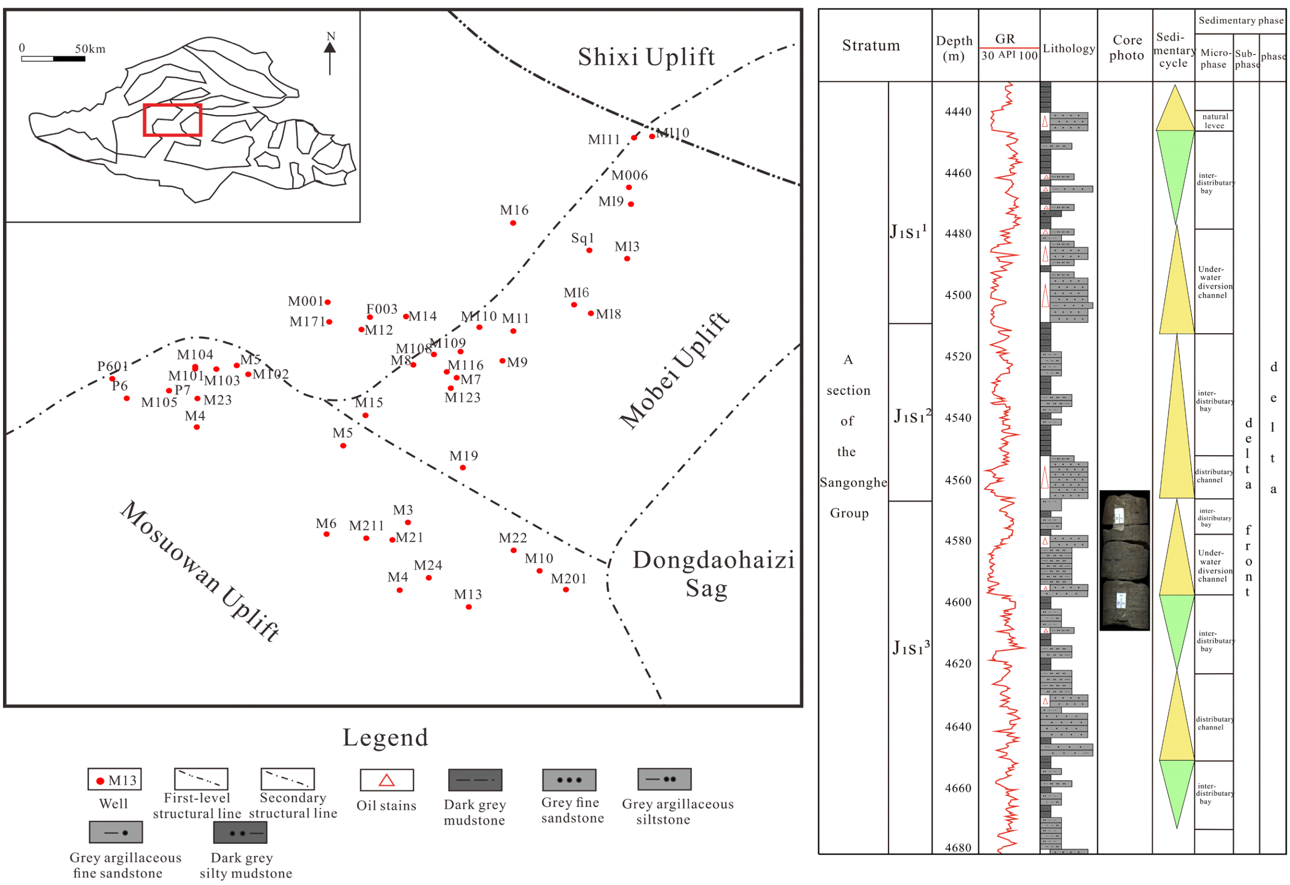


Figure 1. Structural position and stratigraphic comprehensive columnar map of Mosuowan Area, Junggar Basin (modified according to Reference (Lu et al., 2021)).

belongs to the subfacies at the front edge of the delta. The microfacies consist of diverting bays and diverting channels. Estuarine DAMS are not well developed. Sand and sediment are interbedded, and fine-grained sedimentation is dominant (Lu et al., 2021).

4. Basic Characteristics of Reservoirs

4.1. Petrological Characteristics of the Reservoir

The first section of the Sangonghe Formation mainly develops fine sandstone and medium-fine sandstone, followed by medium sandstone. Siltstone, coarse sandstone and unequal-grained sandstone do not develop. The reservoir is characterized by a high content of tuff cuttings and relatively low contents of plastic and rigid cuttings, known as "two lows and one high". The overall content of interstitial substances is relatively low. The proportions of siliceous, carbonate and clay interstitial substances are 0.37%, 2.21% and 2.47% respectively. Among them, clay and carbonate interstitial substances are the main types, followed by siliceous interstitial substances. It can be seen from the sandstone composition classification diagram that the first section of the Sangonghe Formation is mainly composed of developed feldspar cuttings and cuttings (Figure 2). The sandstone has the highest content of cuttings, while the overall content of feldspar and quartz is relatively low, indicating a relatively low compositional maturity.

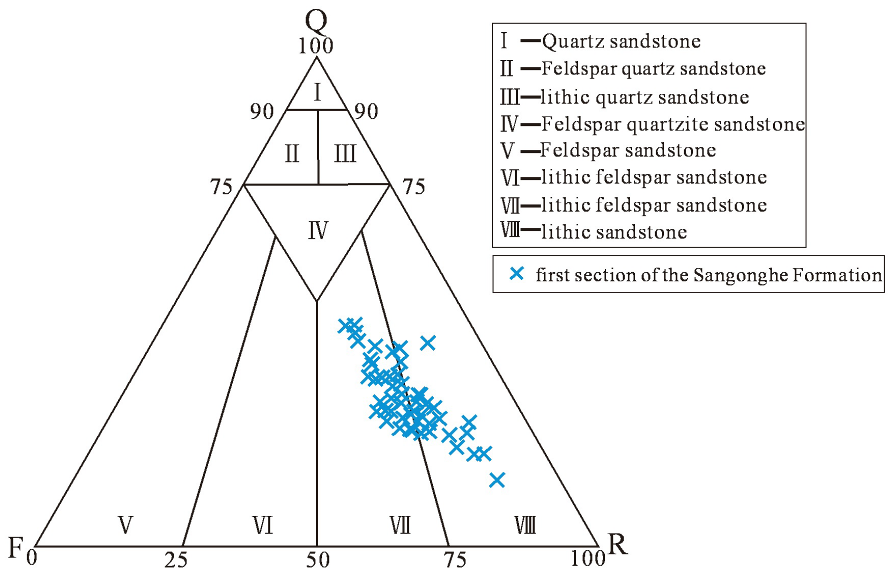


Figure 2. Classification diagram of sandstone composition in the first section of the Sangonghe Formation reservoir in the Mosuowan area.

4.2. Reservoir Rock Particles and Contact Relationship

The sandstone particles in the first section of the Sangonghe Formation are mainly in line contact with less point contact, revealing a strong compaction effect during the sedimentation process and marking the entry of the diagenetic process into the medium-deep burial stage. The particle morphology of sandstone is mainly sub-circular, indicating that the particle transportation distance is moderate. The particle size sorting of sandstone as a whole shows good to medium, indicating that the original sedimentary environment had continuous high-energy water body conditions. Sandstone is dominated by compression cementation, that is, the particles are mainly filled and surrounded by fine-grained substances in the sediment, followed by pore-compression cementation, indicating that the compaction during the diagenetic period is obvious and there is a strong pressure dissolution effect (Figure 3).

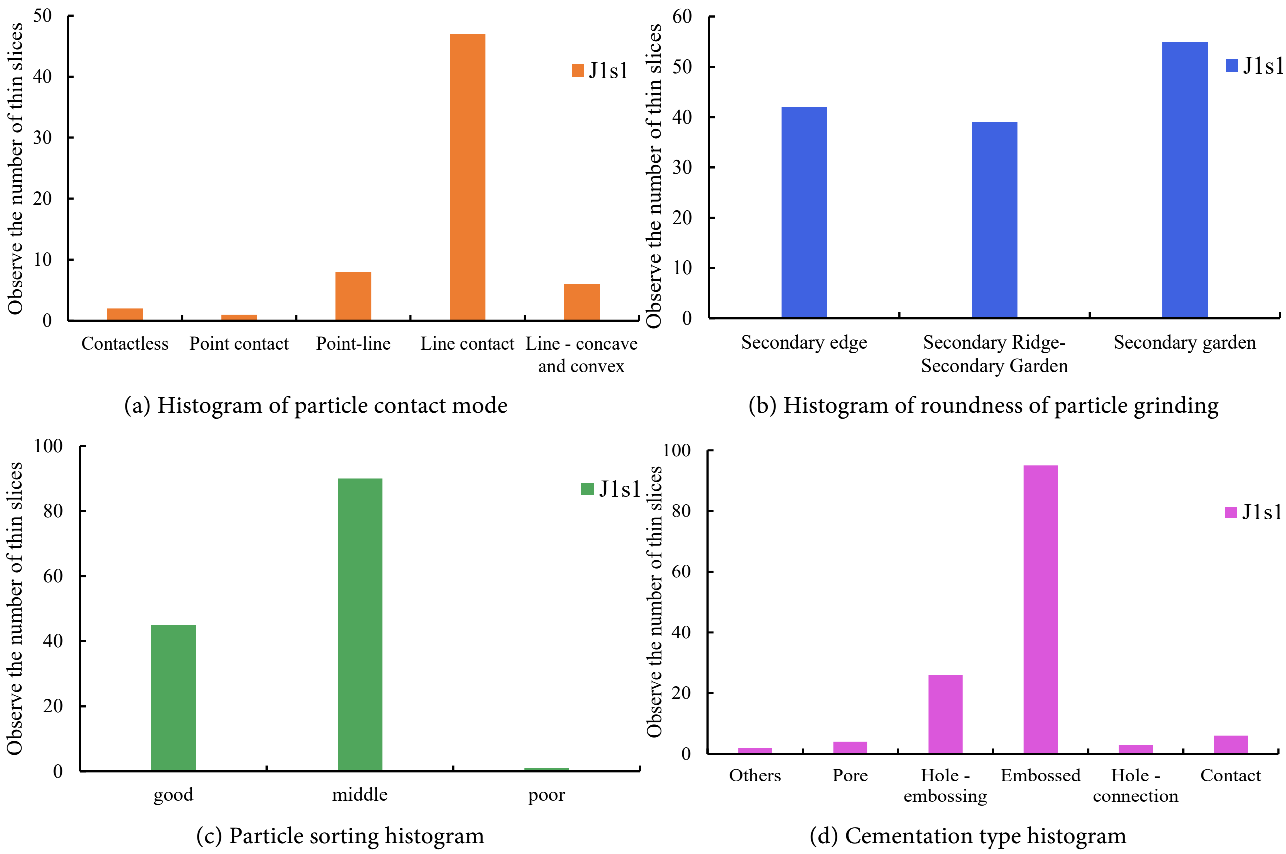
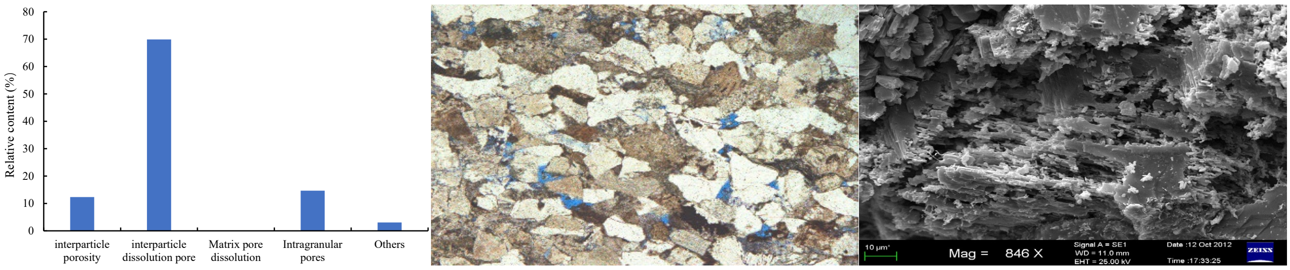


Figure 3. Histogram of rock particles and contact relationship in the first section of the Sangonghe Formation in the Mosuowan area.

4.3. Reservoir Pore Types

The pore types of the reservoirs in the first section of the Sangonghe Formation are mainly secondary pores, with intergranular and intra-granular dissolution pores developed. In addition, there are a small number of primary intergranular pores. Intergranular dissolution pores are mostly formed by the dissolution of intergranular clay impurities. The pores are not restricted by the particle boundaries, have irregular shapes, and their edges are in a harbor shape. Erosion residues are often found at the particle edges (Figure 4). A small number of mold holes can also be seen in the thin sheet. The pores are relatively large and are formed after the particles are fully eroded.



The pore space type of the first section of the Sangonghe Formation

M20, 4416.3 m, $J_1s_1^1$, interparticle dissolution pore, ×50

M21, 4258.7 m, ×846, $J_1s_1^1$, Dissolution pores within feldspar grains

Figure 4. Pore types of the first section of the Sangonghe Formation in the Mosuowan area.

4.4. Reservoir Physical Property Characteristics

Due to the large burial depth, strong compaction and dissolution effect, fine lithologic particles and low comature-maturity of the first section of the Sangonghe Formation reservoir. According to the SY/T 6285-2011 "Evaluation Method for Oil and Gas Reservoirs" standard, the classification boundaries of reservoir porosity are: extremely low porosity ($\varphi < 10\%$), low porosity ($10\% \le \varphi < 15\%$); The permeability classification boundaries are: extremely low permeability (K < 1.0 mD), low permeability (1.0 mD ≤ K < 10.0 mD) (National Energy Administration, 2011). According to the statistical results of the physical property analysis data in the study area, the average porosity of the reservoir is 9.334% (<10%), and the average permeability is 0.482 mD (<1.0 mD). Therefore, it is comprehensively evaluated as an ultra-low porosity and ultra-low permeability reservoir (**Figure 5**).

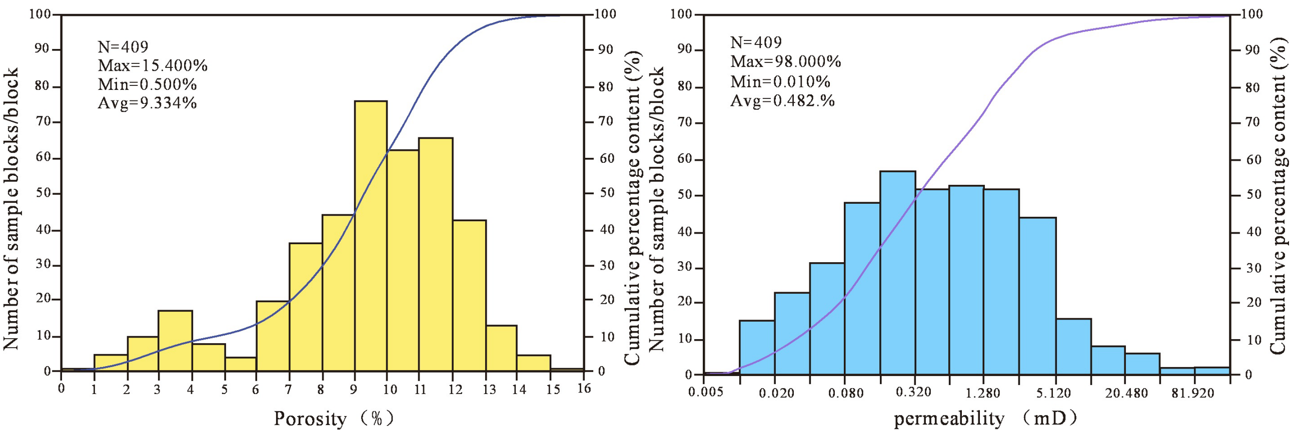
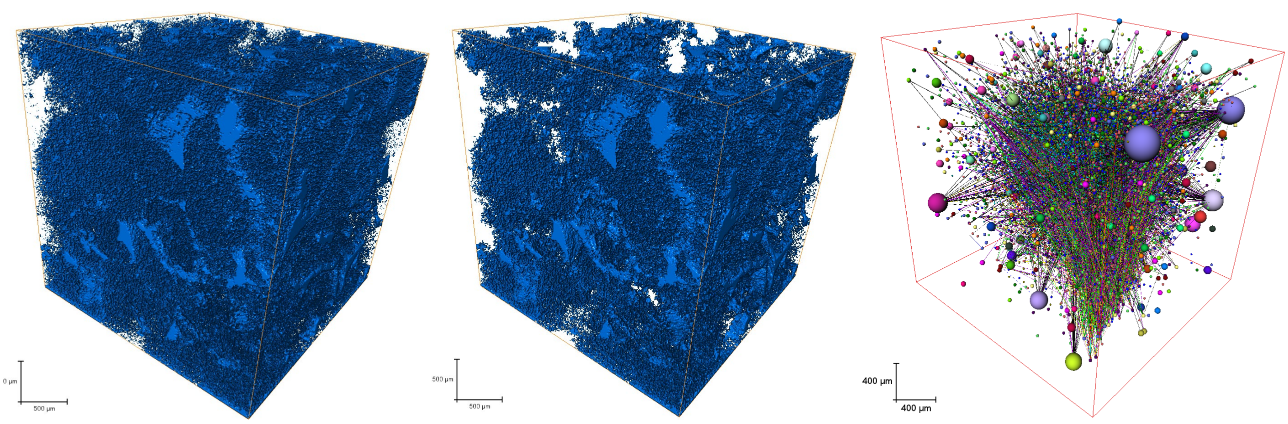


Figure 5. Histogram of physical properties of the first section of the Sangonghe Formation reservoir.

CT scanning analysis technology can quantitatively characterize the three-dimensional microscopic pore structure of sample cores (Zhang et al., 2022). The CT test of the M5 well sample showed that the total porosity was 11.75%, the connected porosity was 7.23%, and the average pore throat coordination number of the reservoir was 0.61. A relatively high proportion of connected pores indicates that the pore structure of the rock has very good connectivity. It can significantly reflect that the rock has undergone intense dissolution, while the influence of compaction and cementation is relatively weak. These effects jointly result in the rock having a high proportion of interconnected pore Spaces. CT scanning technology can reflect the complexity of the internal structure of rocks. The rock skeleton is grayish-white in color, with overall particle size being relatively small. Among them, quartz particles with poor roundness and light tones can be seen, and the Spaces between the particles are filled with a large amount of intercalation materials. The pore distribution in the rock samples is extensive but uneven: in some areas, it is densely clustered, while in the rest, it is relatively sparse. There is connectivity between some pores, which is crucial for fluid flow and storage. The connected network forms flow channels, while the isolated pores mainly serve as storage Spaces (**Figure 6(a)**). The pore distribution is uneven and interconnected, presenting typical characteristics of natural rocks. At the same time, there are a few disconnected pores, making it difficult to form effective seepage channels. The interconnected pores within the rock are dominant, with only local connectivity obstacles existing, indicating the heterogeneous characteristics of strong pores in tight reservoirs (**Figure 6(b)**). The ball stick model can visually present the spatial distribution and connection relationship of the pores and throat channels inside the rock. The spheres represent the pores in the rocks, while the stick-shaped structures simulate the throat channels that connect the pores. The size and number of spheres in the model reflect the porosity of the rock. Porosity is determined by the size and quantity of pore Spaces. As can be seen from the figure, there are numerous pores of various sizes, which indicates that the rock sample has a certain porosity and can store a certain amount of fluid. The permeability of rocks is mainly controlled by the radius of the throat. A larger throat allows fluids to pass through more smoothly, while a smaller throat will cause greater resistance to the flow of fluids (**Figure 6(c)**).



(a) All pores (b) Connected pore (c) Hole-throat ball stick model

Figure 6. Well M5, 4428.63m, J1s11, gas measurement porosity 6.8%, permeability 0.017 mD.

4.5. Reservoir Diagenesis

The porosity and permeability of the sandstone in the first section of the Sangonghe Formation in the Mosuo Bay area decreased rapidly with the increase of burial depth. Mechanical compaction is an important factor for reservoir densification in the study area. The contact methods of particles are mainly line contact and point-line contact, and some point contact and line-concave-convex contact are rare, with no contact at all. The pressure dissolution between particles is obvious, with concave-convex contact or line contact. The cuttings present a pseudo-hybrid base morphology, and the primary intergranular pores are relatively few, which are residual intergranular pores.

5. The Four-Relationship of the Reservoir

5.1. Oil Content and Physical Properties

5.1.1. Relationship between Physical Properties and Oil Content

The oil and gas logging in the sandstone reservoir of the first section of the Sangonghe Formation is mainly characterized by fluorescence and oil traces. According to the statistics of physical property and oil content analysis data (**Figure 7**), the porosity of the samples with fluorescence oil content is mainly concentrated in the range of 1.8% to 12%, with an average of 8.01%. The porosity of the samples with the oil grade of oil stains is mainly concentrated in the range of 2.3% to 12.9%, with an average of 10.43%. The porosity of the samples with oil spots as the oil content grade is mainly concentrated in the range of 6.5% to 13.6%, with an average value of 9.59%. The porosity of the oil-impregnated samples is mainly concentrated in the range of 3.4% to 13.3%, with an average of 10.2%. Comprehensive analysis shows that there is a certain correlation between oil and gas content and physical properties. In both the horizontal and vertical directions, the higher the porosity and permeability values corresponding to the high-value areas of reservoir physical properties, the better the oil content.

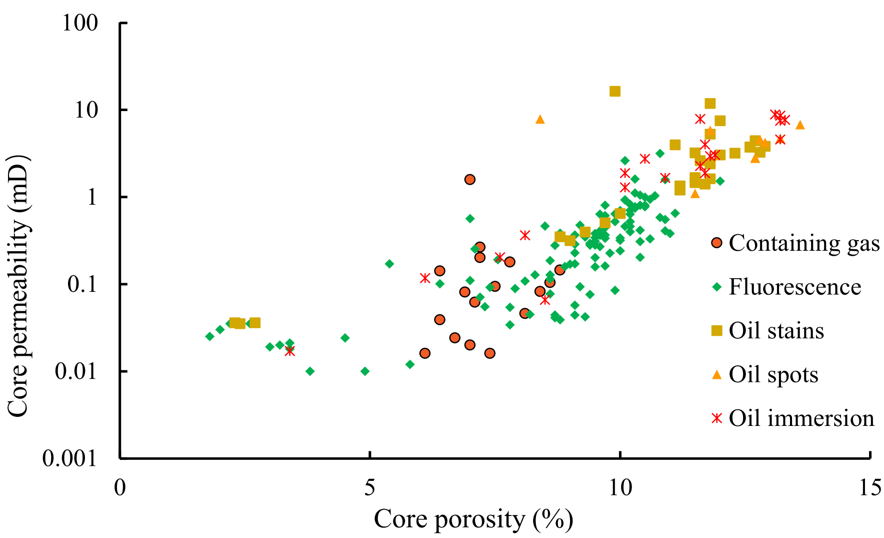


Figure 7. Diagram of the relationship between physical properties and oil content in the first section of the Sangonghe Formation.

5.1.2. The Influence of Physical Property Parameters on Oil Content

The porosity range of the dry layer is from 10.3 to 13.3%, with an average of 11.7%.

Its penetration rate ranges from 0.16% to 2.31%, with an average of 0.68%. The porosity of the oil-containing layer ranges from 7.2 to 13.0%, with an average of 10.2%. Its penetration rate ranges from 0.11% to 1.01%, with an average of 0.39%. The porosity of the water layer ranges from 6.6 to 17.2%, with an average of 12.0%. Its penetration rate ranges from 0.15 to 673.0%, with an average of 3.43%. The porosity of the gas and water in the same layer ranges from 7.6 to 16.0%, with an average value of 12.1%. Its penetration rate ranges from 0.04% to 131.0%, with an average of 2.55%. The porosity of oil and gas in the same layer ranges from 7.5% to 17.9%, with an average of 12.4%. Its penetration rate ranges from 0.16% to 487.0%, with an average of 6.99%. The porosity of the oil and gas layers ranges from 6.9 to 18.6%, with an average of 12.8%. Its penetration rate ranges from 0.14% to 170.0%, with an average of 9.49%.

According to the statistics of the oil test results, physical property analysis results and other data, the oil and gas layer in the first section of the Sangonghe Formation has the best porosity and permeability. Secondly, oil and gas are in the same layer, and gas and water are in the same layer. However, the physical properties of the oil-bearing layer and the dry layer are relatively poor, that is, the parts with better porosity and permeability also have better oil content, showing a positive correlation.

5.2. It Contains Oil and Electricity

The properties of fluids are closely related to the resistivity, acoustic waves, potential, neutron porosity and density of rocks. The samples displayed by fluorescence show a certain range of variation in electrical properties and have no obvious central tendency. The oil stain samples are relatively concentrated, showing the characteristics of high acoustic time difference and low resistivity. The oil spot samples as a whole show a certain aggregation trend, with relatively high resistivity but low acoustic wave time difference. The distribution of oil-immersed samples is also relatively scattered, with a wide range of values for resistivity and acoustic wave time difference. However, some samples also exhibit the characteristics of high resistivity and low acoustic wave time difference. The better the oil content in the first section of the Sangonghe Formation, the lower the acoustic wave time difference, and the poorer the correlation with resistivity (**Figure 8**). The resistivity range is 7.79 - 123.16 Ω·m, and the acoustic wave time difference range is 209.7 - 248.5 μs/m. Within the same depth range, the correlation analysis of oil content with acoustic wave time difference (AC) and resistivity (RT) shows that the correlation coefficient between oil content and AC is −0.077, indicating a very weak negative correlation between the two, that is, the influence of oil content change on the acoustic wave propagation speed is negligible. The correlation coefficient between oil content and RT is −0.302, showing a moderately strong negative correlation, indicating that the resistivity shows a decreasing trend when the oil content increases. This reservoir may have special geological conditions such as high mud content or complex pore structure, which leads to a resistivity response mechanism different from that of conventional sandstone reservoirs.

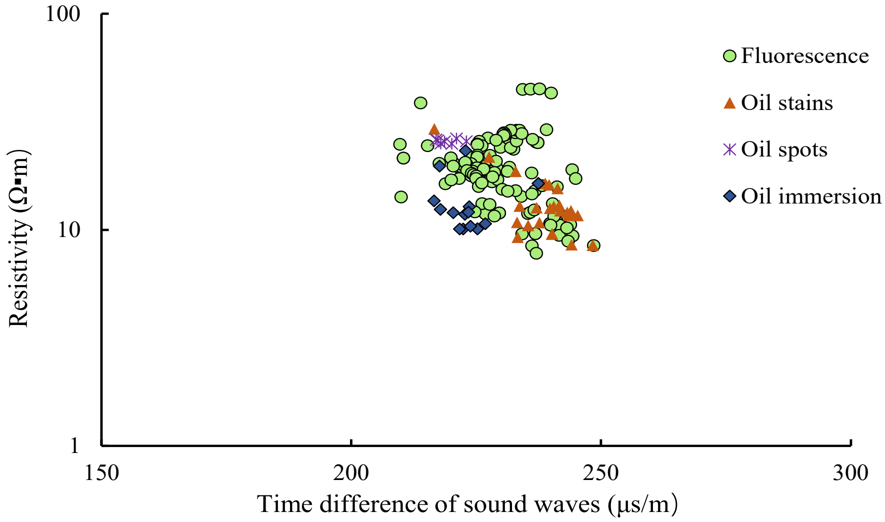


Figure 8. Diagram of the relationship between oil content and electricity in the first section of the Sangonghe Formation.

5.3. Oil Content and Lithology

The oil and gas content varies with different types of rocks. Even for the same type of rock, different particle sizes can lead to different oil and gas contents. According to the statistical results of lithological oil content grades, fine sandstone and medium-fine sandstone have the most oil and gas display results, followed by medium sandstone, and argillaceous siltstone has the least oil and gas display results. Meanwhile, the oil and gas display level of medium and fine sandstone is the highest, while fine sandstone and medium sandstone mainly show fluorescence (Figure 9).

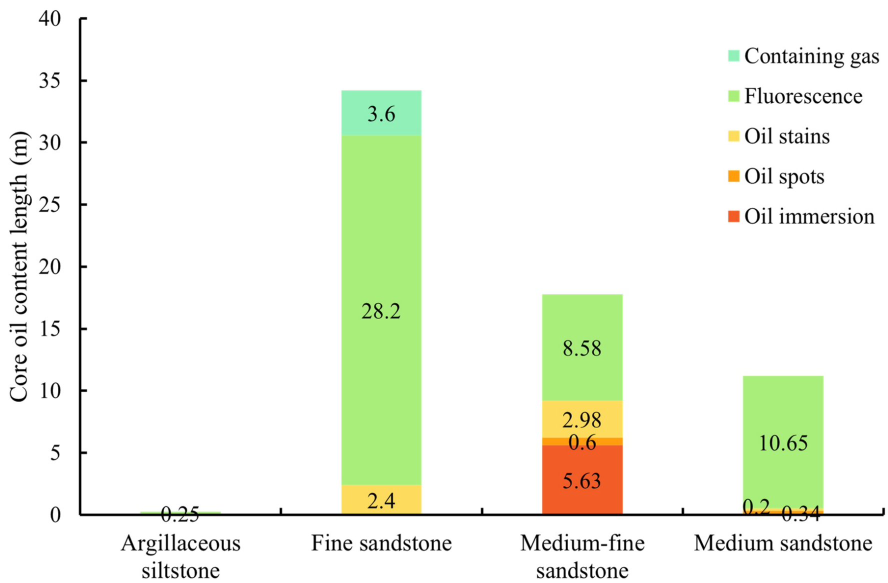


Figure 9. Diagram of the relationship between lithology and oil content in the first section of the Sangonghe Formation.

5.4. Lithology and Physical Properties

The first section of the Sangonghe Formation mainly consists of medium and fine sandstone, medium sandstone and fine sandstone (Figure 10). The reservoirs have the characteristic that the coarder the lithology and grain size, the better the physical properties. The porosity distribution range of mudstone is 0.5% - 6.8%, with an average value of 4.23%. The permeability distribution range is 0.037 mD-18.9 mD, with an average value of 2.05 mD. The porosity distribution range of siltstone is 3.2% - 6.4%, with an average value of 4.5%. The permeability distribution range is 0.015 mD - 0.179 mD, with an average value of 0.066 mD. The porosity distribution range of fine-grained sandstone is 1.4% - 7.7%, with an average value of 5.01%. The permeability distribution range of fine-grained sandstone is 0.01 mD - 2.29 mD, with an average value of 0.46 mD. The porosity distribution range of fine sandstone is 3% to 12%, with an average of 8.56%. The distribution range of permeability is 0.01 mD - 81.5 mD, with an average value of 1.56 mD. The porosity distribution range of medium and fine sandstone is 6.1% - 13.9%, with an average value of 11.03%. The distribution range of permeability is 0.017 mD - 71.2 mD, with an average value of 3.25 mD. The porosity distribution range of the middle sandstone is 7.1% - 13.1%, with an average value of 10.24%. The distribution range of permeability is 0.01 mD - 16.3 mD, with an average value of 2.06 mD. The porosity distribution range of unequal-grained sandstone is 13.2% - 15.4%, with an average value of 14.24%. The permeability distribution range is 1.65 mD - 84.5 mD, with an average value of 34.73 mD. The best porosity is achieved by unequal-grained conglomerate, followed by medium-fine sandstone.

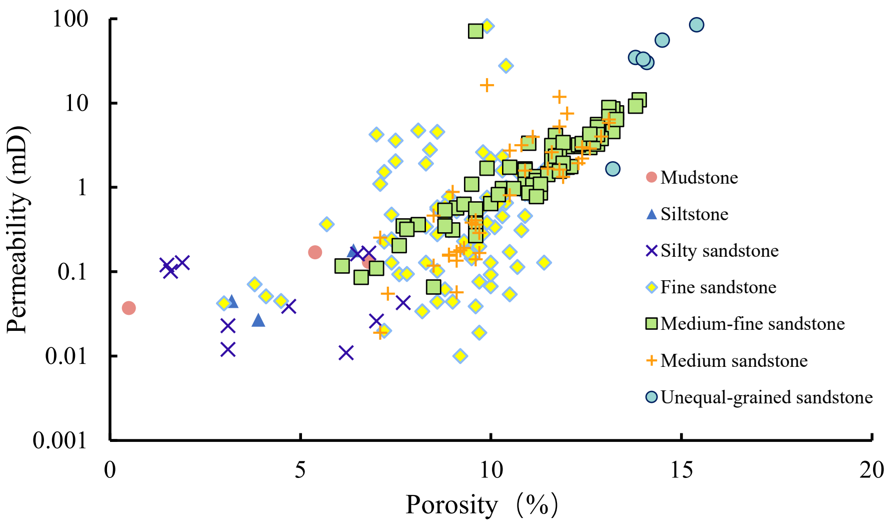


Figure 10. Diagram of lithology and physical relationship in the first section of the Sangonghe Formation.

5.5. Lithology and Electrical Properties

According to the logging and lithological data, the lithology of the first section of the Sangonghe Formation in the study area mainly consists of fine sandstone, fine sandstone, medium-fine sandstone and medium sandstone. Through the analysis of five logging curves of four lithologies in the first section of the Sangonghe Formation and the statistics of the average logging values (**Table 1**), the characteristics of the logging curves corresponding to different lithologies were distinguished: Fine-grained sandstone shows the features of low acoustic time difference, low natural potential value and high gamma. Fine sandstone exhibits the characteristics of high natural potential values and low gamma values. Medium-fine sandstone exhibits the characteristics of low density curves and low resistivity. Middle sandstone exhibits the characteristics of high acoustic time difference and high density.

Table 1. Statistical distribution of logging parameters for different lithologies in the first section of the Sangonghe Formation.

Lithology / Electricity	Average value				
	AC	DEN	GR	RT	SP
Silty sandstone	69.316	2.43	73.0175	19.559	−38.3515
packsand	69.85214	2.509716	62.6243	19.53331	0.373932
Medium-fine sandstone	69.993	2.42117	67.47162	17.04072	−36.9202
Medium sandstone	71.2103	2.533909	63.27409	18.67597	−6.47418

6. Conclusion

The lithology of the first section of the Sangonghe Formation is mainly feldspar cuttings sandstone and cuttings sandstone, and the overall maturity of its composition is relatively low. The reservoir sandstone is mainly fine-grained and medium-fine-grained, followed by medium-grained. This section of the reservoir is characterized by a significantly high content of tuff cuttings, while the contents of plastic and rigid cuttings are relatively low. The filling effect of the three types of cuttings leads to the complication of the pore throat structure, forming a multilevel pore network, which results in a decrease in the effective permeability of the reservoir. Comprehensive physical property analysis indicates that the reservoir in this section as a whole exhibit's dual characteristics of low to extremely low porosity and low to extremely low permeability, and its pore structure and seepage capacity have significant heterogeneity.

The medium and fine sandstone in the first section of the Sangonghe Formation has a relatively good oil content, and the oil and gas layers are developed in the parts with the best porosity and permeability. The second is the coexistence of oil and gas in the same layer and gas and water in the same layer. However, the physical properties of the oily layer and the dry layer are relatively poor. The oil content grade is closely related to porosity: from the oil layer, gas layer to the oil layer, the pore channel radius shows a decreasing trend, while the median pressure increases accordingly. The coarser the lithological grain size of the reservoir, the better the physical property characteristics, and the degree of pore throat development is directly proportional to the oil content.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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