Scientific Research Publishing

**Journal of Geoscience and Environment Protection, 2025, 13(9), 108-124**
https://www.scirp.org/journal/gep
ISSN Online: 2327-4344
ISSN Print: 2327-4336

# Causes and Mechanisms of the Badaowan Formation Reservoir on the Southern Slope of the Mahu Depression

**Ze Zhao**[1,2], **Jing Liu**[1,2]

[1]School of Earth Science and Engineering, Xi'an Shiyou University, Xi'an, China
[2]Shaanxi Key Laboratory of Hydrocarbon Accumulation Geology, Xi'an Shiyou University, Xi'an, China
Email: 232164608@qq.com

**How to cite this paper:** Zhao, Z., & Liu, J. (2025). Causes and Mechanisms of the Badaowan Formation Reservoir on the Southern Slope of the Mahu Depression. *Journal of Geoscience and Environment Protection, 13,* 108-124.
https://doi.org/10.4236/gep.2025.139006

**Received:** August 13, 2025
**Accepted:** September 19, 2025
**Published:** September 22, 2025

## Abstract

The Jurassic Badaowan Formation on the southern slope of the Mahu Sag has a shallow burial depth and abundant oil and gas resources. On the basis of clarifying the basic characteristics of the reservoir, an in-depth analysis is conducted on the control of sedimentation and diagenesis on the reservoir genesis. The reservoir is mainly composed of lithic sandstone and feldspathic lithic sandstone; the types of reservoir space are mainly intergranular pores and intragranular pores, belonging to a low-porosity and ultra-low-permeability reservoir. The sedimentary environment is the underwater distributary channel of the delta front subfacies, and the distribution of sedimentary facies determines the distribution of sand bodies. Compaction is the main factor destroying primary pores. The changes in reservoir physical properties are mainly controlled by sedimentation and diagenesis. Sedimentation lays the material foundation for reservoir formation, while diagenesis plays a role in later transformation of the reservoir. The research results can provide ideas and directions for the next exploration and development of the Mahu Sag.

## Keywords

Mahu Sag, Badaowan Formation, Reservoir Characteristics, Genetic Mechanism

## 1. Introduction

The Mahu Sag is one of the core target areas in the oil and gas exploration field of the Junggar Basin (Wu et al., 2022; Wang et al., 2023; Chen et al., 2018; Hou et al., 2017). Current research results are all based on the analysis and research related to the sedimentary and reservoir-forming characteristics of the Badaowan Formation. The research on the genetic mechanism of the Badaowan Formation reservoir is not yet systematic. The study of the reservoir genetic mechanism can accurately predict the distribution of favorable reservoirs for exploration, improve the exploration success rate and save costs. At the development level, it can clarify the reservoir heterogeneity and then optimize the development plan. For the late-stage development, it can help tap the potential of remaining oil, extend the development life of the reservoir, and improve the development efficiency of oil and gas fields (Song, 2020; Ma et al., 2018) Therefore, analyzing many geological processes such as the type of cement, pore structure and basic characteristics, particle sorting, and diagenesis of the reservoir, and finally clarifying the controlling factors of reservoir formation can provide theoretical reference and practical experience for the next-step oil and gas exploration work.

## 2. Study Area Overview

The western side of the Mahu Sag is bounded by the Kebai Fault Zone, the northern side is adjacent to the Wuxia Fault Zone, and the southern side forms a basin margin contact zone with the Zhongguai Uplift. On the eastern side, the Dabason Uplift, Xiayan Uplift, Yingxi Sag, and Shiyingtan Uplift are successively distributed from south to north, forming an intra-basin secondary tectonic framework with alternating uplifts and sags (Qin et al., 2023; Qian et al., 2025). Since the Permian, the tectonic evolution of the Mahu Sag and its periphery in the Junggar Basin can be divided into four stages. Each stage has distinct stratigraphic characteristics. The foreland fault-depression period (Lower Permian $P_1j$ - $P_1f$) is characterized by thick strata near the footwall of the thrust nappe and thin strata near the lake basin area; the fault-depression to depression transition period (Middle Permian $P_2x$ - $P_2w$) shows the trend of thinning strata near the fault zone and gradually thickening strata near the lake basin area; the early depression filling period (Upper Permian $P_3w$ - Lower Triassic $T_1b$) is manifested by thick strata near the lake basin area and thin strata near the provenance area; the depression period (Middle Triassic $T_2k$ - Jurassic J-Cretaceous K) with approximately equal stratum thickness within the sag range(Meng et al., 2024).

The study area is located on the southern slope of the Mahu Sag. The Badaowan Formation was formed in the early Mesozoic Jurassic. Its stratum thickness ranges from 70 to 700 meters. The overlying stratum is the Sangonghe Formation, and the underlying stratum is the Baijiantan Formation. The lower part of this formation consists of gravel-bearing non-equal-grained sandstone, thin and thick interbeds of fine sandstone and glutenite; the middle part is argillaceous siltstone; the upper part is mainly gray medium-fine sandstone, intercalated with thin and thick interbeds of gray mudstone and shale, and a small amount of coal seams locally appear. $J_1b$ is a braided river delta front deposit, which is subdivided into the first member ($J_1b_1$), the second member ($J_1b_2$), and the third member ($J_1b_3$) of the Badaowan Formation, mainly developing sedimentary microfacies such as inter-distributary channels, underwater distributary channels, and interfluve bays (**Figure 1**).

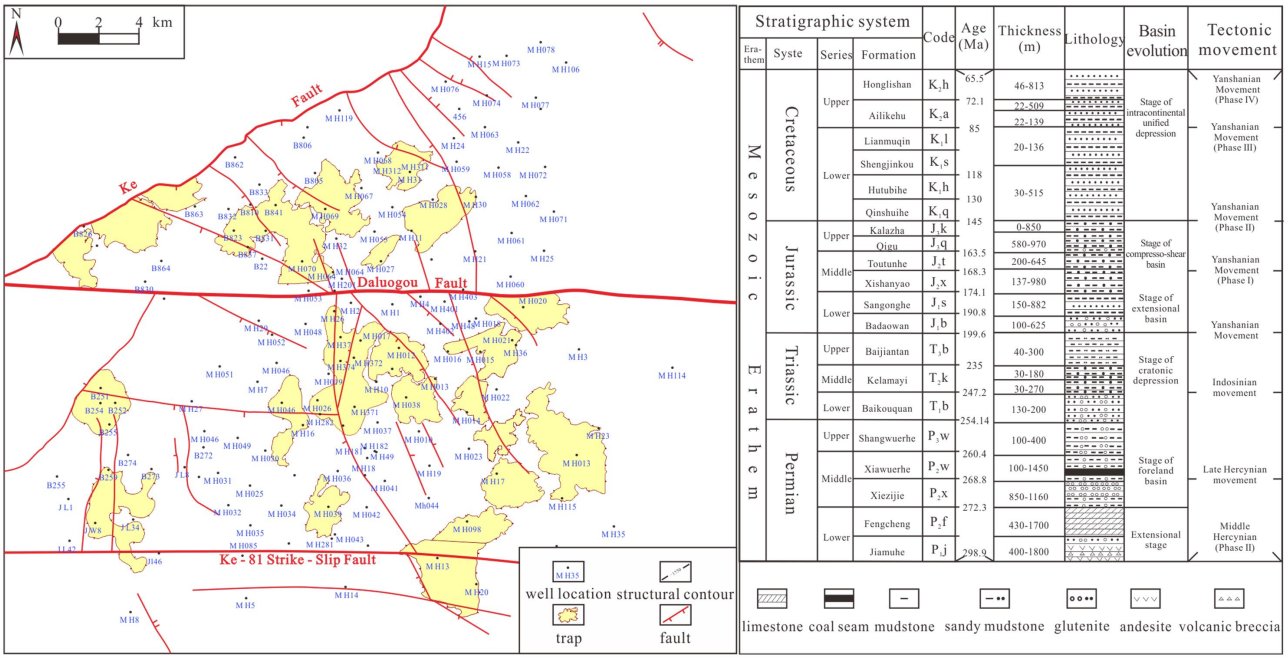

**Figure 1.** Location map of the study area and comprehensive stratigraphic columnar section (modified according to reference (He et al., 2018)).

## 3. Reservoir Characteristics

### 3.1. Petrological Characteristics

In the south slope of Mahu Sag, the quartz and feldspar grain contents in the Badaowan Formation reservoir are relatively low, and the lithology is mainly lithic sandstone and feldspathic lithic sandstone. In the rock mineral composition, the average contents of quartz, feldspar, and lithic fragments are 25.56%, 11.65%, and 62.79% respectively (**Figure 2**). The detrital components are relatively abundant, mainly including granite, andesite, phyllite, tuff, mica, etc. (**Table 1**). The matrix is mainly kaolinite, followed by micrite siderite; the cements are mainly ferrocalcite, siderite, etc. In terms of rock texture, the particle shape is mainly subrounded, and the sorting degree is between moderate and good; in terms of cementation type, the pressure-embedded type is dominant, followed by the pressure-embedded-pore type.

### 3.2. Physical Properties and Characteristics of Reservoir Spaces

The physical properties of the reservoir are the key factors determining its reservoir performance, and the magnitudes of porosity and permeability are the intuitive manifestations of the physical properties. Core samples were measured three times in duplicate using a Micromeritics AutoPore V instrument for mercury intrusion capillary pressure (MICP) measurements (pore range: 0.1 - 300 μm). The measurement process followed the ASTM D4404-10 standard. A total of 28 core samples and 25 mercury intrusion analysis samples were collected from 8 wells in the study.

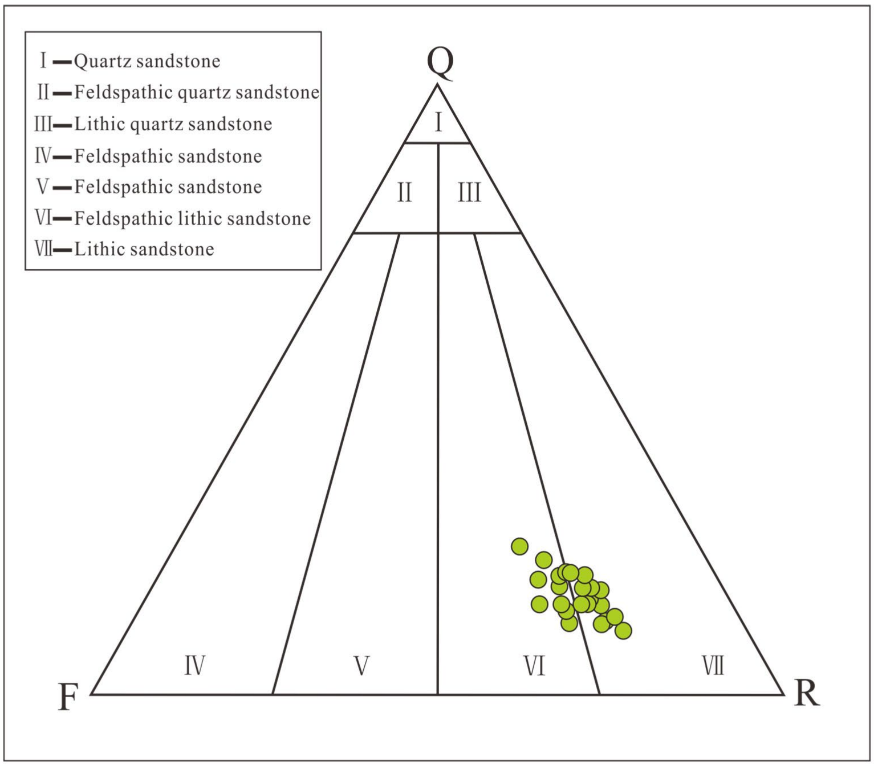

**Figure 2.** Sandstone classification triangular diagram of the badaowan formation on the southern slope of the mahu sag.

**Table 1.** Statistics table of lithological and mineralogical compositions of the badaowan formation on the south slope of the mahu sag.

| Stratum | | | Badaowan Formation |
|---|---|---|---|
| Quartz/% | | | 25.56 |
| Feldspar/% | | | 11.65 |
| Rock debris/% | Igneous rock | Granite | 6.20 |
| | | Andesite | 2.08 |
| | | Felsite | 6.74 |
| | Metamorphic rock | Siliceous rock | 1.64 |
| | | Phyllite | 2.17 |
| | | Mica quartz schist | 1 |
| | | Quartzite | 1.83 |
| | | Rhyolite | 5.71 |
| | Sedimentary rock | Carbonate clastics | 2 |
| | | Yuff | 31.86 |
| | Siderite pellets | | 1.13 |
| | Mica | | 0.16 |
| | Other | | 0.27 |
| Sample/block | | | 35 |

The measured permeability of the reservoir is mainly distributed between 0.1 and 10 mD, with an average of 1.88 mD. It can be seen that the Badaowan Formation reservoir belongs to a low-porosity and ultra-low-permeability reservoir (**Figure 3(a)**). The measured porosity of the core of the Badaowan Formation reservoir is mainly distributed between 6.0% and 14.0%, with an average of 11.2% (**Figures 3(b)**). The types of reservoir space in this reservoir are mainly intergranular pores and intragranular pores, followed by structural fractures. Among them, intragranular pores are mostly developed in rock fragments and are formed by dissolution (**Figure 4**).

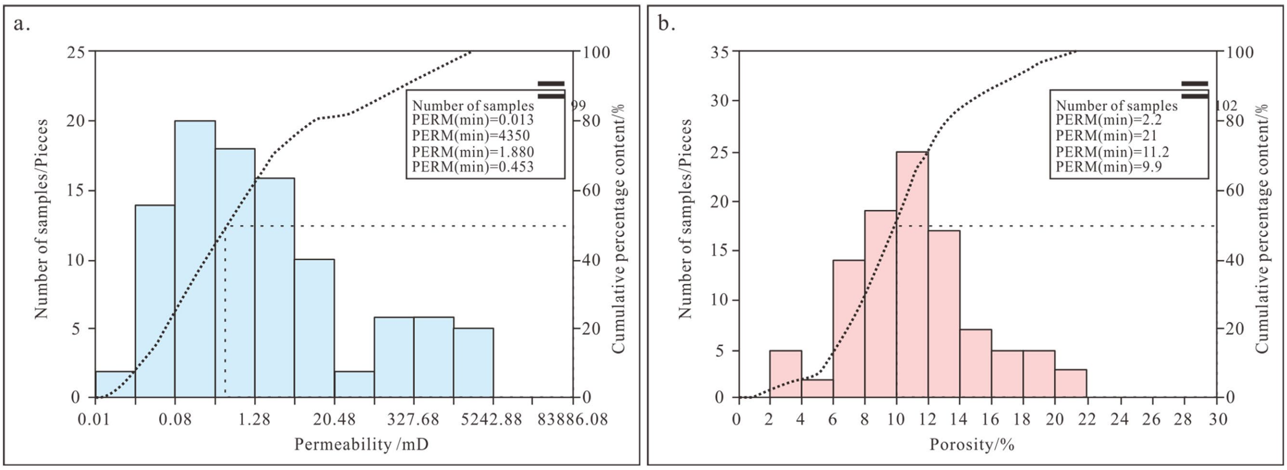

**Figure 3.** Histogram of physical property frequency distribution in the bayidaowan formation (a. Permeability frequency distribution histogram; b. Histogram of porosity frequency distribution)

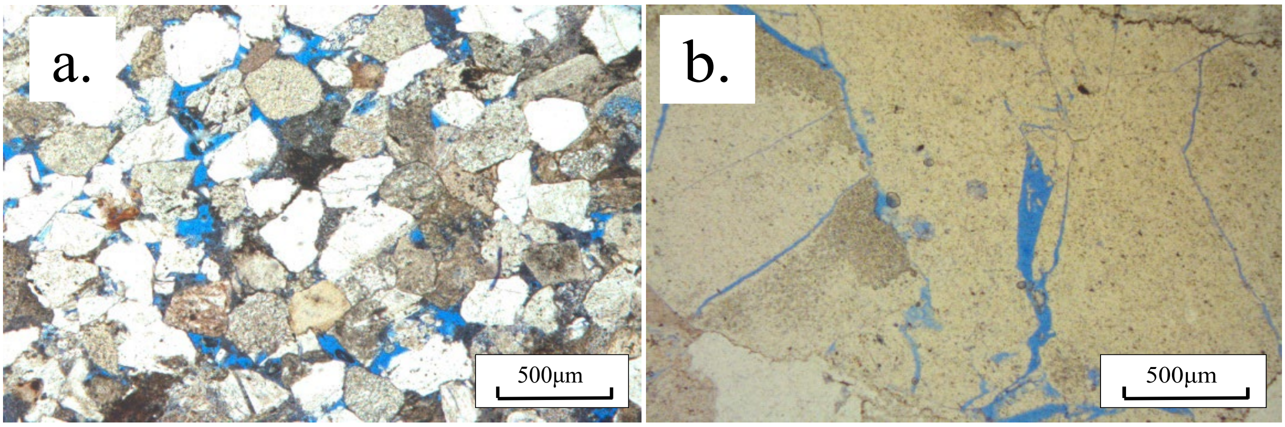

**Figure 4.** Histogram of permeability frequency distribution in Bayidaowan Formation(a. MH Well 12, 2799.00 m, $J_1b_1$, ×50; b. MH Well 13, 3015.63 m, $J_1b_1$, ×100)

This study is limited by the small sample size (28 cores and 25 mercury intrusion samples), which may affect regional extrapolation. The data mainly reflect the local differences within the study area; more extensive applications need to be verified with additional samples to explain the corresponding variations. Future research should incorporate a larger number of samples and sample types to expand the spatial coverage.

### 3.3. Pore Structure

The microscopic pore structure of the reservoir directly affects the seepage capacity of the reservoir. The parameters obtained from the mercury injection experiment are used to quantitatively describe the pore structure of the reservoir, and the impacts of the pore-throat size, sorting, and connectivity of the reservoir on the reservoir physical properties are analyzed. The correlation relationships between the four parameters characterizing the pore-throat size, namely the displacement pressure, median pressure, median radius, and mean coefficient of the reservoir, and the permeability are clarified. It is found that the displacement pressure and median pressure are negatively correlated with the permeability, while the median radius and mean coefficient are positively correlated with the permeability. That is, the above laws indicate that the larger the pore-throat (corresponding to the decrease in displacement pressure and median pressure, and the increase in median radius and mean coefficient), the greater the permeability of the reservoir (**Figure 5**).

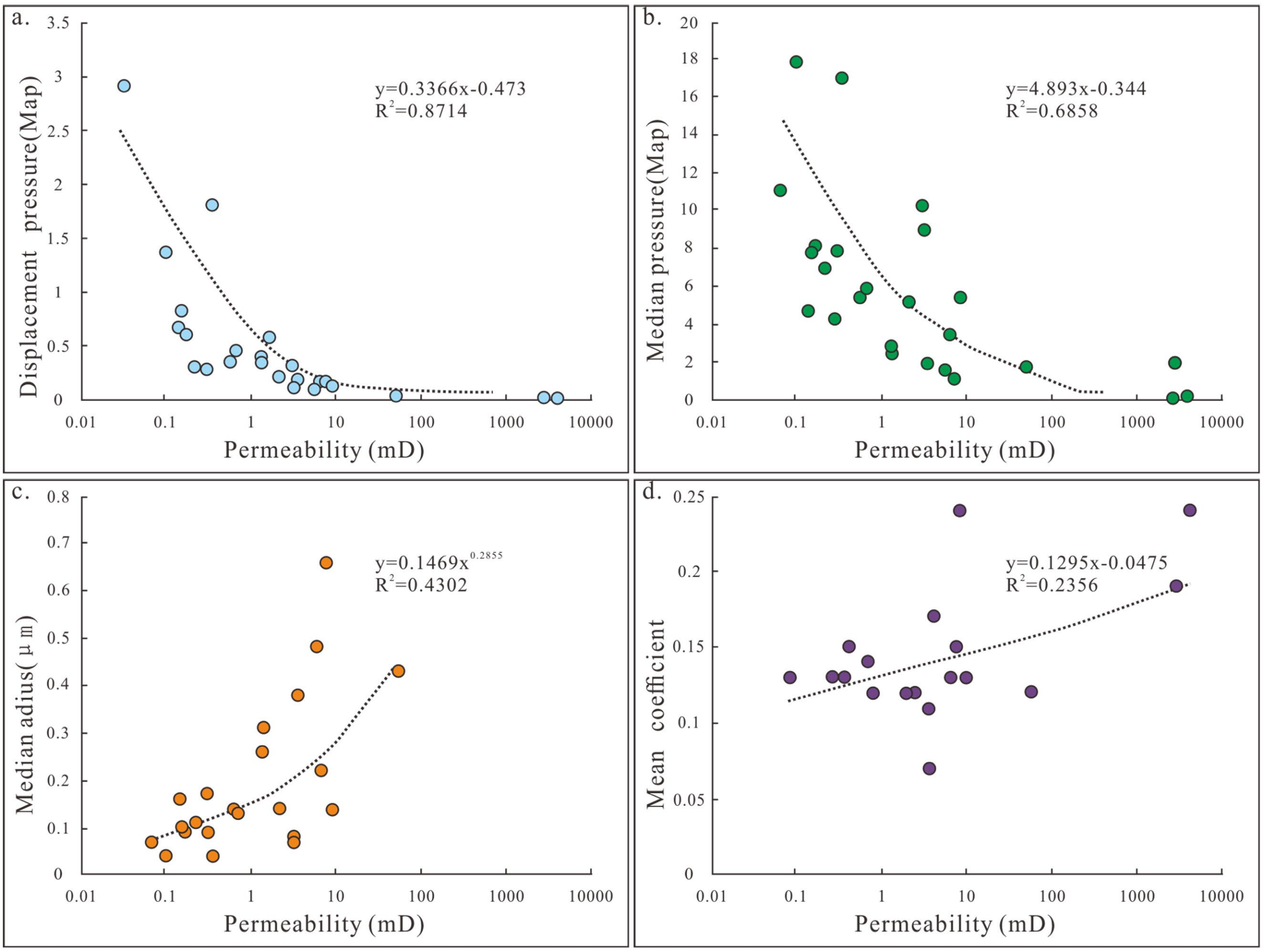

**Figure 5.** Relationship diagram between pore-throat size characterization parameters and permeability of the Badaowan Formation.

Parameters characterizing the pore-throat sorting characteristics mainly include the pore-throat sorting coefficient and the coefficient of variation. Generally, the lower the pore-throat sorting coefficient, the better the pore-throat sorting and the more uniform the distribution. The coefficient of variation also follows this rule, and theoretically, both are negatively correlated with reservoir permeability.

However, an abnormal phenomenon occurs in the target layer section of the study area: both the pore-throat sorting coefficient and the coefficient of variation are positively correlated with permeability (**Figure 6**). This particularity is closely related to the inherent properties of the Badaowan Formation reservoir. Since this reservoir is of the low-porosity and low-permeability type, with complex pore types, and a large number of small throats are developed, occupying the vast majority of the throat space, which greatly limits the conventional performance of the sorting coefficient and the coefficient of variation.

The situation where the rock permeability increases with the increase of the sorting coefficient (σ) needs to be comprehensively judged in combination with the characteristics of the pore-throat system and geological action conditions. There are mainly two cases: First, when there is partial dissolution of framework particles in the rock (such as the dissolution of feldspar and carbonate cements), the increase in the sorting coefficient (σ ≈ 1.2 - 1.8) is accompanied by fine-grained materials that could potentially block the pore throats. However, the formation of secondary large pores will offset this negative effect and form supplementary channels for fluid flow, thus increasing the permeability with the increase of the sorting coefficient. Second, in rocks dominated by primary pores and without secondary pores, when the sorting coefficient increases from the medium sorting stage (σ ≈ 1.2 - 1.8), the particles are loosely stacked due to the moderate difference in particle size, forming a pore network with better connectivity and moderate throat width. Compared with rocks with good sorting (where particles are closely packed and throats are narrow) or extremely poor sorting (where the proportion of fine grains is too high and throats are blocked), the permeability is higher. However, this rule requires the preconditions of no strong cementation, pores not filled with cement, and the sorting coefficient only "moderately increasing" (not reaching the extremely poor level). Essentially, it is the coupling effect

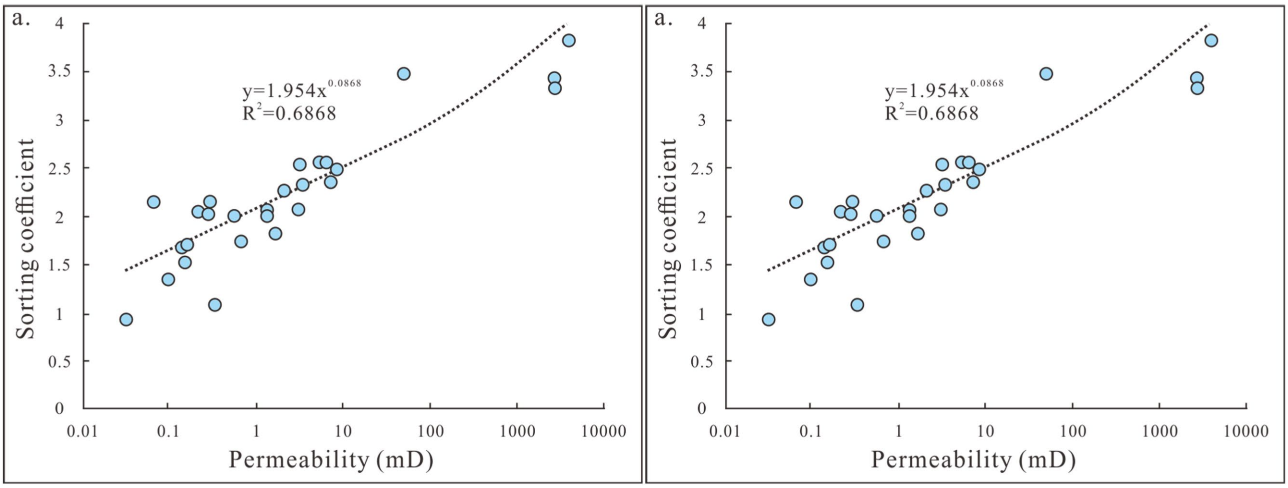

**Figure 6.** Relationship diagram between pore-throat sorting characterization parameters and permeability of the Badawan Formation.

of the influence of the sorting coefficient on the pore-throat connectivity and the development of secondary pores or the particle packing structure. The core is to ensure that the fluid flow channels (throats) are not blocked and have good connectivity (Lei et al.,2022).

Specifically, when the pore-throat sorting coefficient of the reservoir is high, it actually reflects a deterioration in pore-throat sorting, but at this time, the frequency of large throats will increase accordingly; and the increase in large throats can effectively improve the reservoir permeability, ultimately resulting in this curve relationship that does not conform to the typical law.

Generally speaking, the larger the maximum pore-throat radius and the higher the mercury withdrawal efficiency, the better the connectivity of the pore-throat, and the higher the permeability of the sandstone. The maximum pore-throat radius of the Badaowan Formation is positively correlated with the permeability, while the mercury withdrawal efficiency is negatively correlated. The reason for the decrease in mercury withdrawal efficiency is the strong microscopic heterogeneity of the reservoir and the uneven distribution of pore sizes. When the sorting coefficient is large, the permeability is only a representation of the large porosity, and the pore-throat connectivity is poor. As a result, a large amount of mercury remains in the small pores after mercury withdrawal, thus reducing the mercury withdrawal efficiency (**Figure 7**).

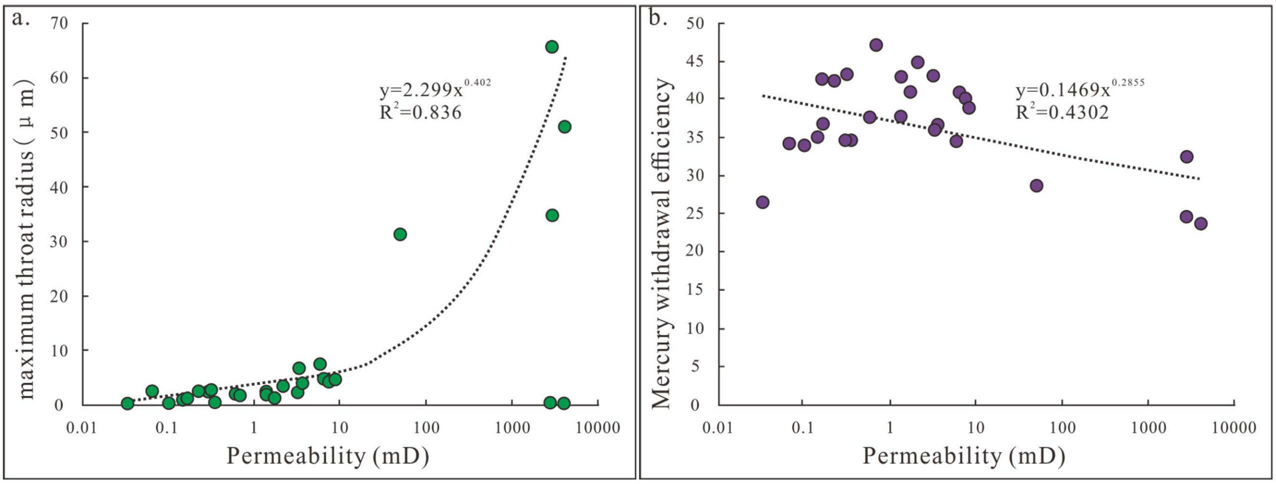

**Figure 7.** Relationship diagram between pore-throat connectivity characterization parameters and permeability in the Badaowan Formation.

According to the mercury injection data analysis, the pore structure characteristic types of the Badaowan Formation can be divided into three categories: I, II, and III, representing good reservoirs, poor reservoirs, and very poor reservoirs respectively. Among them, the pore-throat combination of type I reservoirs is mainly medium pores and medium throats, with medium porosity and medium permeability, well-developed pores, and the typical capillary pressure curve shape is fine skewness. The pore-throat combination of type II reservoirs is mainly relatively fine pores and relatively fine throats, with low porosity and low permeability, poor physical properties, and poorly developed pores, and the typical capillary pressure curve shape is extremely fine skewness. The pore-throat combination of type III reservoirs is mainly fine pores and fine throats, with low porosity and low permeability, poor physical properties, and poorly developed pores, and the typical capillary pressure curve shape is extremely fine skewness (Table 2).

**Table 2.** Pore characteristics table of the badaowan formation on the south slope of the mahu sag.

| Category | Pore Characteristics | Throat Characteristics | Physical Property Performance | Curve Morphology |
|---|---|---|---|---|
| Type I | Medium | Medium | Relatively Good | Slightly Fine |
| Type II | Relatively Fine | Relatively Fine | Poor | Moderately Fine |
| Type III | Fine | Fine | Poor | Fine |

The pore structure samples of the Badaowan Formation on the southern slope of the Mahu Sag are classified into types I, II, and III. Among them, type I has an average permeability of $172.0 \times 10^{-3}$ μm$^2$, an average displacement pressure of 0.23 MPa, an average median pressure of 3.64 MPa, an average median radius of 1.11 μm, and an average capillary radius of 3.57 μm. Type II has an average permeability of $1.28 \times 10^{-3}$ μm$^2$, an average displacement pressure of 0.54 MPa, an average median pressure of 9.35 MPa, an average median radius of 0.09 μm, and an average capillary radius of 0.54 μm. Type III has an average permeability of $0.568 \times 10^{-3}$ μm$^2$, an average displacement pressure of 1.86 MPa, an average median pressure of 5.70 MPa, an average median radius of 0.01 μm, and an average capillary radius of 0.16 μm (Table 3).

**Table 3.** Comprehensive classification table of pore structures in the badaowan formation on the south slope of the mahu sag.

| Stratigraphic Horizon | Badaowan Formation | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Category | Type I | | | Type II | | | Type III | | |
| Statistical Range | Max | Min | Avg | Max | Min | Avg | Max | Min | Avg |
| Porosity (%) | 20.3 | 11.2 | 13.84 | 10.7 | 9 | 9.66 | 7.8 | 7.3 | 7.5 |
| Permeability ($10^{-3}$ μm$^2$) | 4010.0 | 71.6 | 172.0 | 3.23 | 0.067 | 1.28 | 1.66 | 0.01 | 0.568 |
| Median Saturation Pressure (MPa) | 8.08 | 0.08 | 3.64 | 17.8 | 4.69 | 9.35 | 17.11 | 0.00 | 5.70 |
| Median Saturation Radius (μm) | 9.57 | 0.09 | 1.11 | 0.16 | 0.04 | 0.09 | 0.04 | 0.00 | 0.01 |
| Displacement Pressure (MPa) | 0.61 | 0.01 | 0.23 | 1.37 | 0.11 | 0.54 | 2.91 | 0.57 | 1.86 |
| Maximum Pore Radius (μm) | 65.58 | 1.21 | 12.66 | 6.8 | 0.54 | 2.51 | 1.30 | 0.25 | 0.63 |
| Average Capillary Radius (μm) | 18.11 | 0.3 | 3.57 | 1.22 | 0.14 | 0.54 | 0.31 | 0.06 | 0.16 |
| Pore-Throat Volume Ratio (%) | 3.25 | 1.12 | 1.81 | 1.95 | 1.24 | 1.63 | 2.80 | 1.46 | 2.20 |
| Unsaturated Pore Volume Percentage (%) | 32.87 | 5.05 | 21.61 | 46.52 | 23.76 | 32.30 | 62.41 | 44.88 | 53.35 |
| Mercury Withdrawal Efficiency (%) | 47.11 | 23.54 | 36.80 | 44.64 | 33.87 | 38.45 | 40.71 | 26.30 | 32.35 |
| Number of Samples | 20 | | | 7 | | | 3 | | |

## 4. Analysis of the Genetic Mechanism of the Reservoir

### 4.1. Authors and Affiliations

The sedimentary environment of the Bachu Formation reservoir in the study area is mainly the delta front sub-facies, and the main reservoir is the underwater distributary channel micro-facies. From the relationship between sedimentary facies characteristics and sand-body distribution, the underwater distributary channels are distributed in a continuous sheet, and the distribution of sand-bodies is controlled by the distribution of sedimentary facies. Specifically, the sand-bodies in the distributary channel area have a large thickness and good physical properties. When extending to both sides of the channel, the sand-bodies gradually thin. The position of the inter-distributary bay is unstable, and its sediments are mainly mudstone, silty mudstone, dense fine-grained sandstone interbedded with mudstone, etc. Compared with the sand-bodies in the distributary channel area, the physical properties are significantly worse. However, this dense layer in the inter-distributary bay can form a good barrier layer, which can effectively prevent the lateral migration of oil and gas, and is very

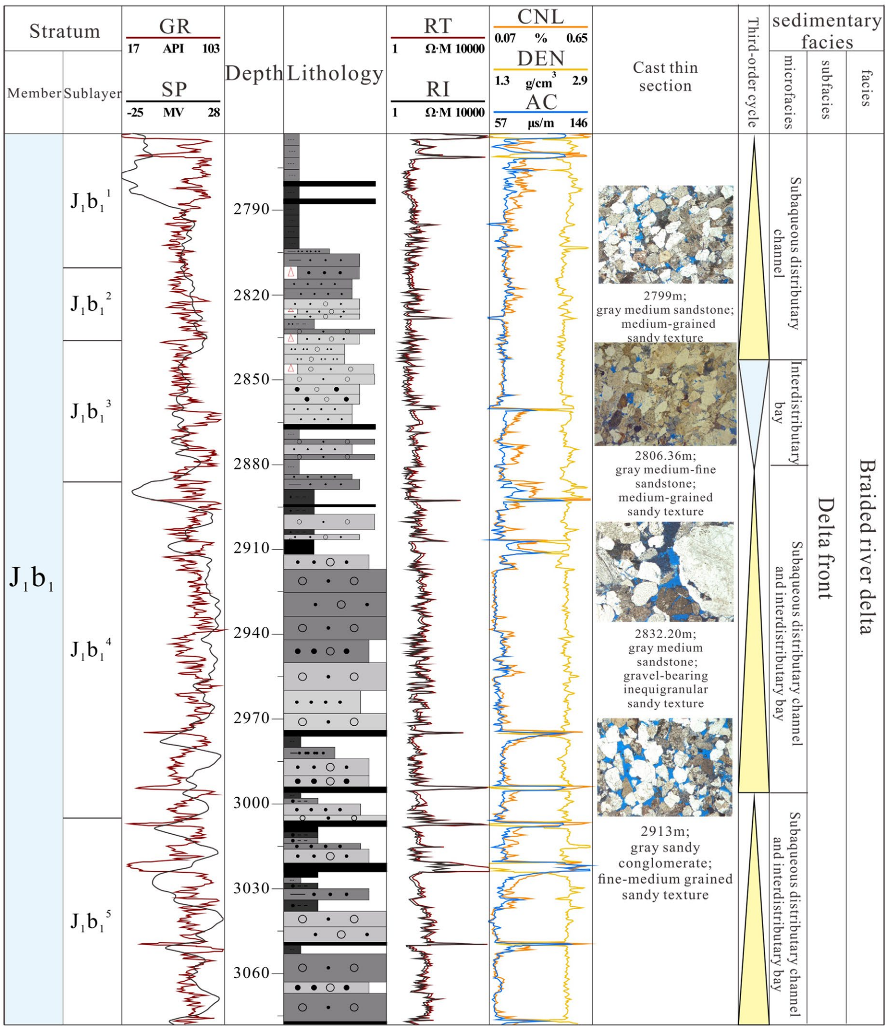

**Figure 8.** Division of single well sedimentary cycle and sedimentary facies of MH Well 12.

beneficial to the enrichment and accumulation of oil and gas (Figure 8).

Subaqueous distributary channels are the main places for sand body accumulation. The areas with large sand body thickness correspond to the development positions of subaqueous distributary channels (Figure 9). The transportation and deposition of water flow thicken the sand bodies. In Figure 10, the areas with better porosity mostly overlap with the areas with large sand body thickness in Figure 9. Because the sand bodies deposited in subaqueous distributary channels have moderate grain size, good sorting and rounding, which are conducive to the formation of reservoirs with good connectivity and well-developed pores. That is, the development areas of subaqueous distributary channels (thick sand body areas) are often the areas with better porosity. The spatial distributions of the two are related, reflecting the controlling effect of sedimentary facies on reservoir physical properties.

## 4.2. The Transformation of Reservoirs by Diagenesis

Before the sediment is transformed into sedimentary rock after deposition until the occurrence of metamorphism, or before it is uplifted to the surface by tectonic movement and undergoes weathering, the influence of physical, chemical, biological and other factors it experiences is collectively referred to as diagenesis. This

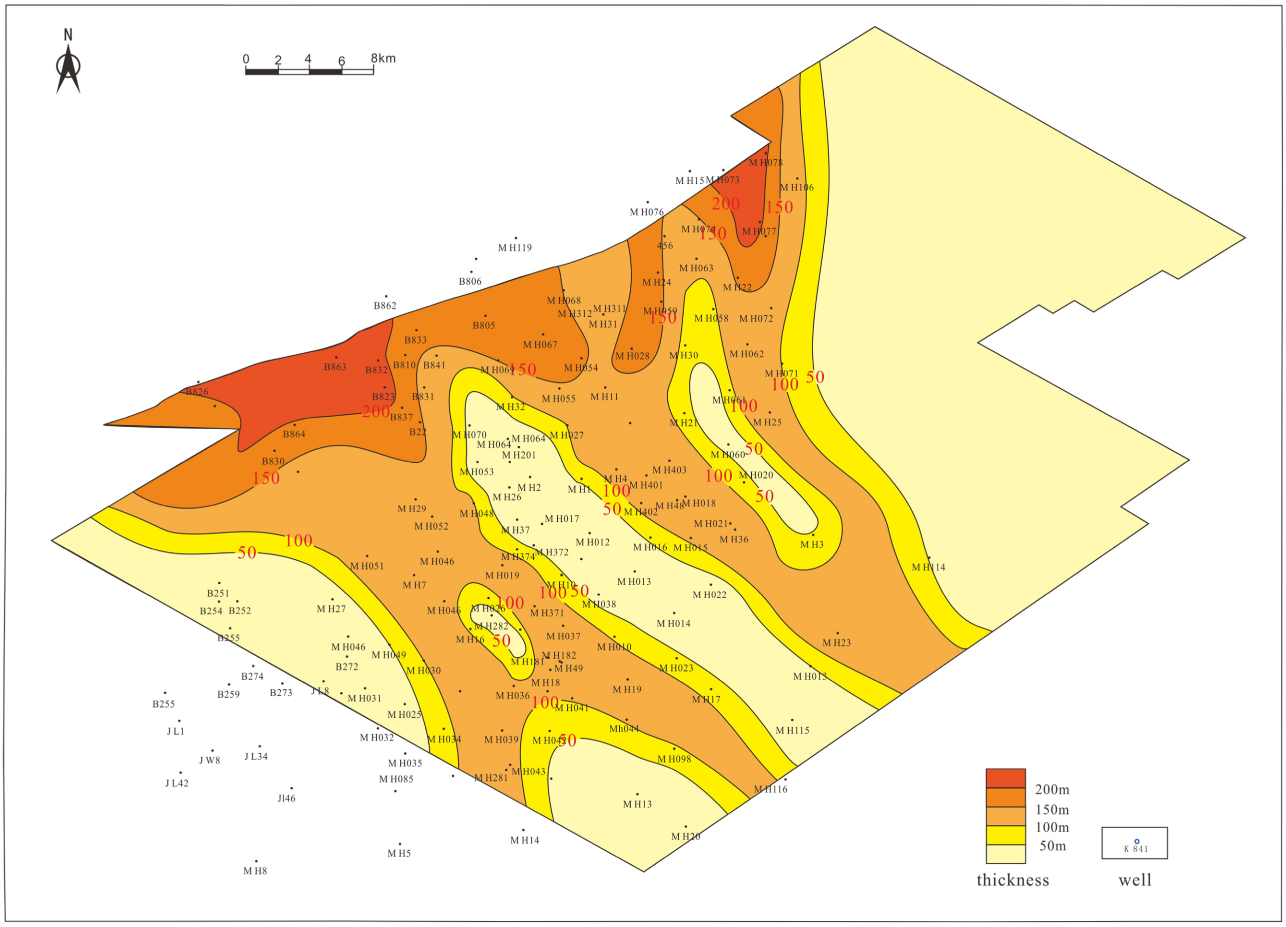

Figure 9. Isoline map of $J_1b_1$ sand body thickness.

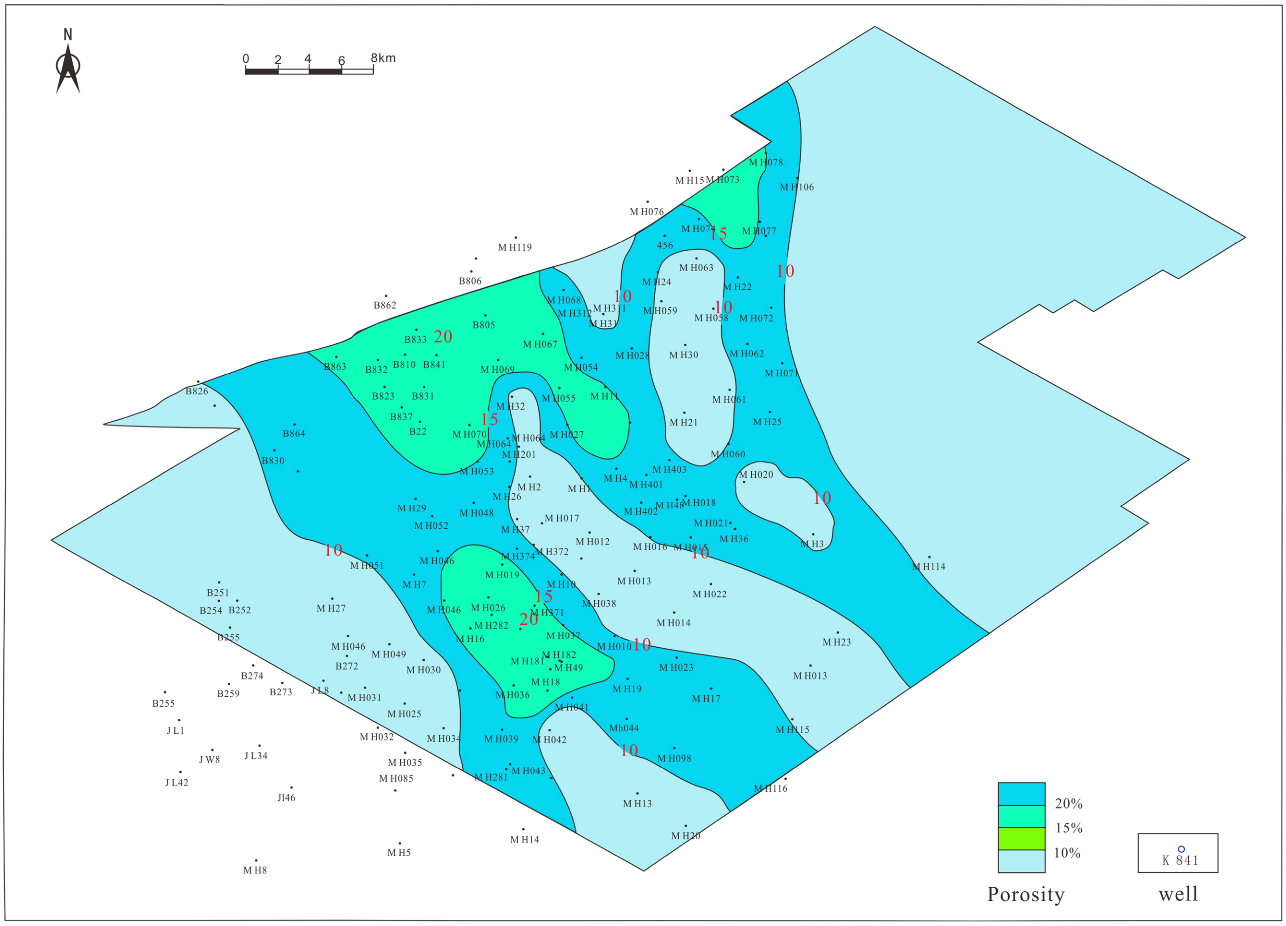

Figure 10. Contour map of porosity in $J_1b_1$ reservoir.

process can change the composition, structure and texture of the rock, thus leading to changes in the number, type, structure and permeability of reservoir pores. For the reservoir of the Badaowan Formation, the diagenesis that occurs mainly includes compaction, pressure solution, cementation, dissolution and metasomatism.

Compaction and pressure solution are remarkable in the strata of the Badaowan Formation. Affected by overlying gravity, hydrostatic pressure and tectonic deformation stress, the particles in this stratum are arranged closely and directionally, causing the pore fluid to be expelled and resulting in poor physical properties. Plastic particles such as phyllite debris and mica are bent and deformed. At the same time, intense mechanical compaction also causes the fracture of rigid particles such as quartz, feldspar and volcanic debris. The detrital particles are mainly in linear contact, and some show sutured contact, indicating the existence of pressure solution (**Figure 11**).

Since the porosity loss caused by mechanical compaction is irreversible, it is a destructive diagenesis. Its macroscopic effect is that with the increase of burial depth, the physical properties of sandstone deteriorate, which is the main factor for the decline of reservoir physical properties in the study area.

Cementation is also one of the important reasons for reducing the porosity and

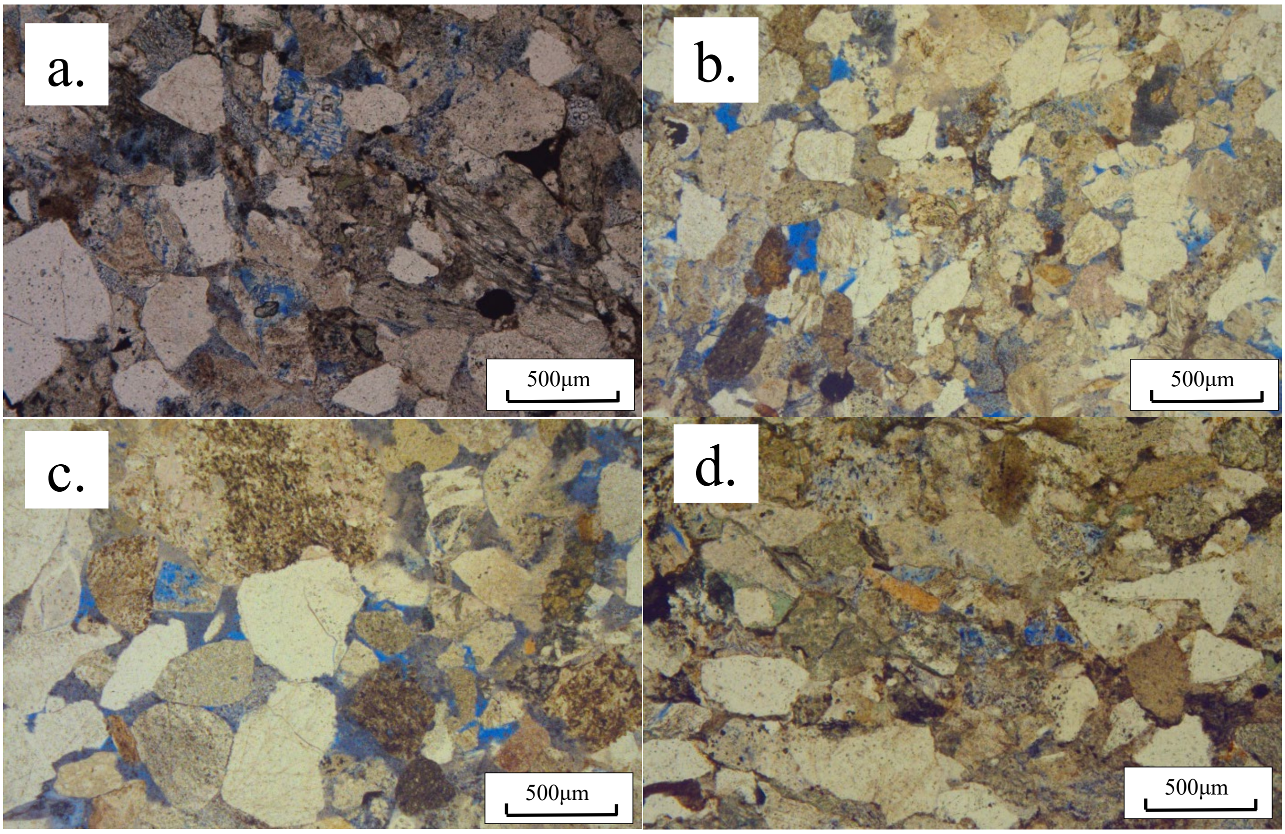

**Figure 11.** Observation of cast thin sections of the badowan formation reservoir (Compaction) (a. MH Well 201, 2429.5 m, $J_1b_1$, ×50, mica deformation; b. MH Well 12, 2806.36 m, $J_1b_1$, ×50, The clastics are directionally distributed;c. MH Well 13, 3013.06 m, $J_1b_1$, ×50, particle breakage; d. MH Well 13, 3050.67 m, J1b1, ×50, linear contact between particles).

permeability of the reservoir and damaging the reservoir. According to the different cements, cementation can be subdivided into calcite cementation, clay mineral cementation, illite cementation, illite-smectite mixed-layer cementation, etc. The cementation of the Bachuwan Formation reservoir is generally relatively developed, and the main cementation types include ferrocalcite cementation, siliceous cementation (quartz overgrowth), and clay mineral cementation.

The cementation of carbonates has a certain destructive effect on the reservoir. Although some calcite dissolution pores may appear, the improvement effect of these dissolution pores on the physical properties of the reservoir is not obvious. The carbonate mineral cementation in the Bachuwan Formation is relatively weak, mainly ferrocalcite cementation is observed. Calcite is distributed in a star-like shape, and dolomite cement is sporadically developed locally (Figure 12).

The formation of quartz secondary enlargement rims is formed by the growth and connection of silica dissolved in formation water with the surface of clastic particles as a common substrate. In the Badaowan Formation, quartz secondary enlargement generally grows towards the pores, filling the pores, thereby blocking the throats and reducing the physical properties of the reservoir. Siliceous cementation is relatively common in the clastic rocks within this formation. Quartz grains mostly show irregular narrow-rimmed secondary enlargement, playing a role in cementing clastic particles (Figure 13).

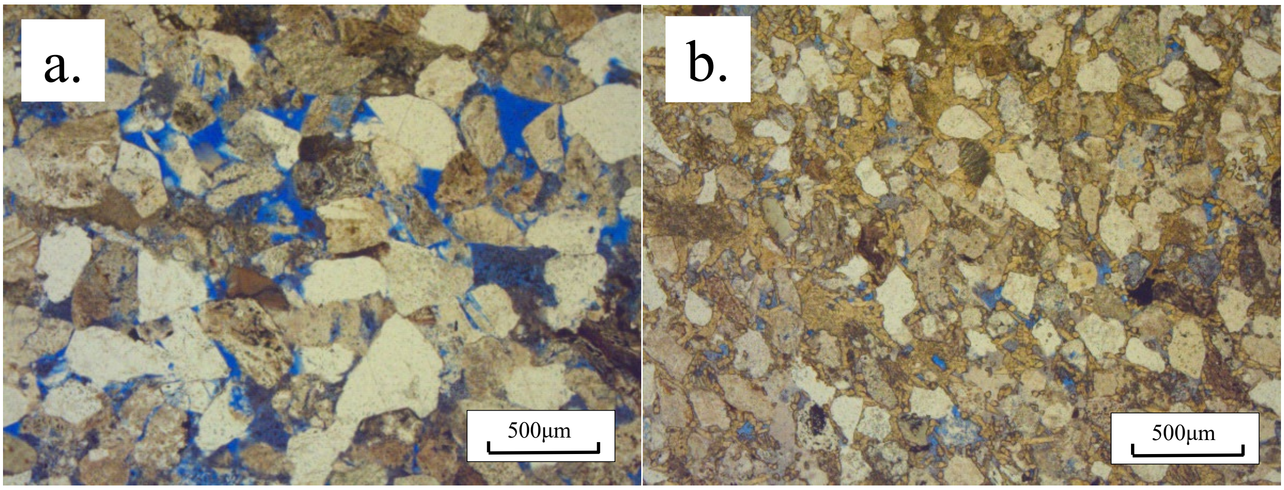

Figure 12. Carbonate cementation of the Badowan Formation reservoir (a. MH Well 12, 2801.5 m, $J_1b_1$, ×100, Calcite is distributed in star-shaped dots. b. MH Well 13, 2928.25 m, $J_1b_1$, ×50, dolomite cement).

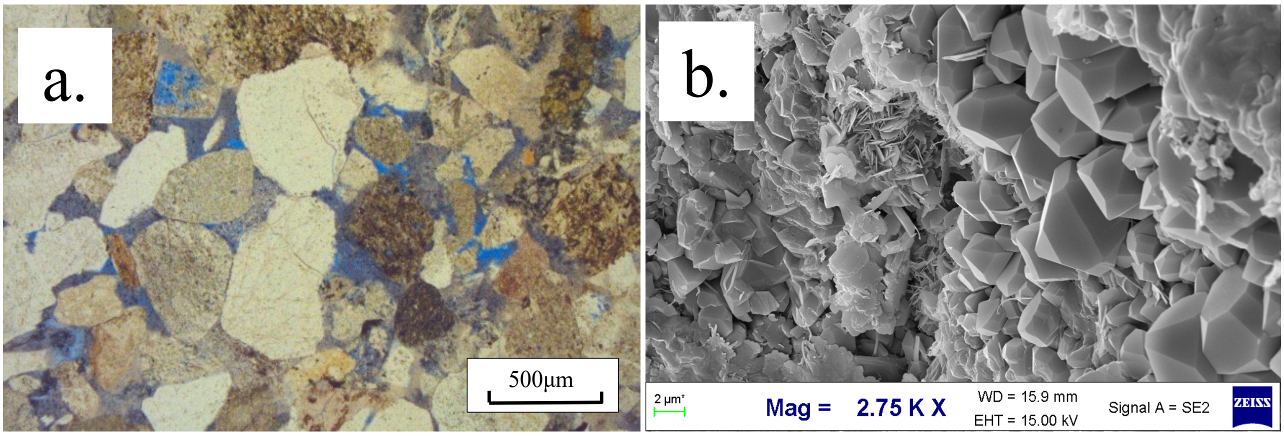

Figure 13. Observation of cast thin sections of the badawan formation reservoir (siliceous cementation) (a. MH Well 13, 3013.06 m, $J_1b_1$, ×100, quartz secondary; b. MH Well 13, 2929.52 m, $J_1b_1$, ×100, quartz secondary enlargement rim).

The morphology and properties of authigenic clay minerals lead to a two-sided impact on the physical properties of the reservoir. Authigenic clay minerals filling between pores will directly occupy the pore space and reduce the porosity of the reservoir, thus playing a destructive role in the reservoir physical properties at this time. However, clay films with special properties and occurrences can protect the remaining intergranular pores. Common authigenic clay mineral cements in the sandstones of the Badaowan Formation include kaolinite, illite, chlorite, and illite/smectite mixed-layer minerals (Figure 14). Among them, chlorite mainly appears in two ways: chlorite films and aggregates filling pores. While reducing the porosity, it can also impede the further reaction between pore water and grains, limit the development of quartz secondary enlargement, and is conducive to the preservation of primary pores. In contrast, coarse-crystalline kaolinite, book-like and filament-like illite filling pores will lead to a decrease in the reservoir porosity.

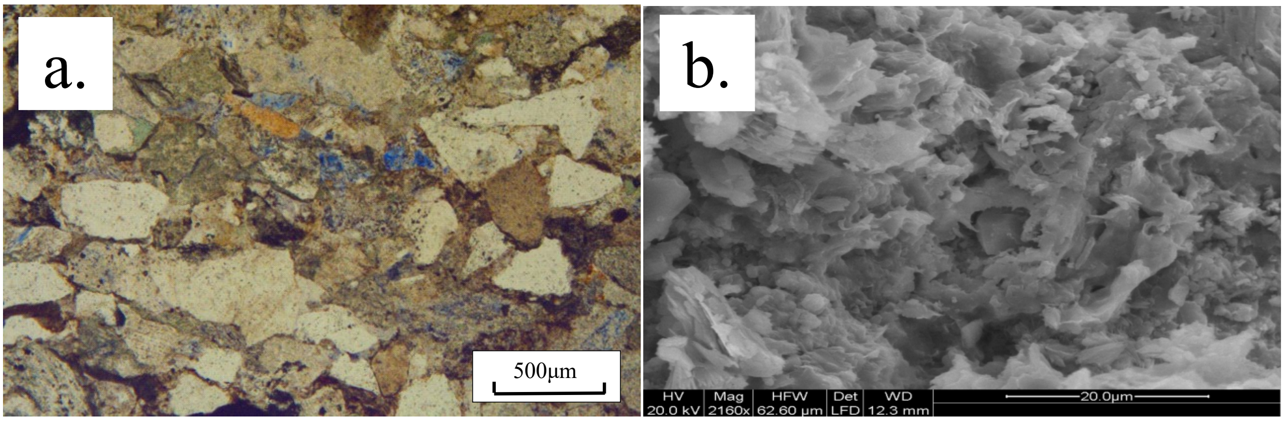

**Figure 14.** Observation of thin sections of the Badawan Formation reservoir (clay mineral cementation) (a. MH Well 13, 3050.67 m, $J_1b_1$, ×50, chlorite cementation; b. MH Well 13, 2929.52 m, $J_1b_1$, ×100 illite cementation).

Dissolution is a common type of diagenesis in sandstones, which has a good effect on improving reservoir physical properties. Dissolution widely exists in the target layers of the study area. Dissolution phenomena commonly occur in various soluble components in reservoir rocks, mainly soluble detrital grains, followed by matrix and cements (Figure 15). This process provides a certain proportion of secondary pores for the Badaowan Formation, improves the physical properties of the reservoir, and belongs to constructive diagenesis.

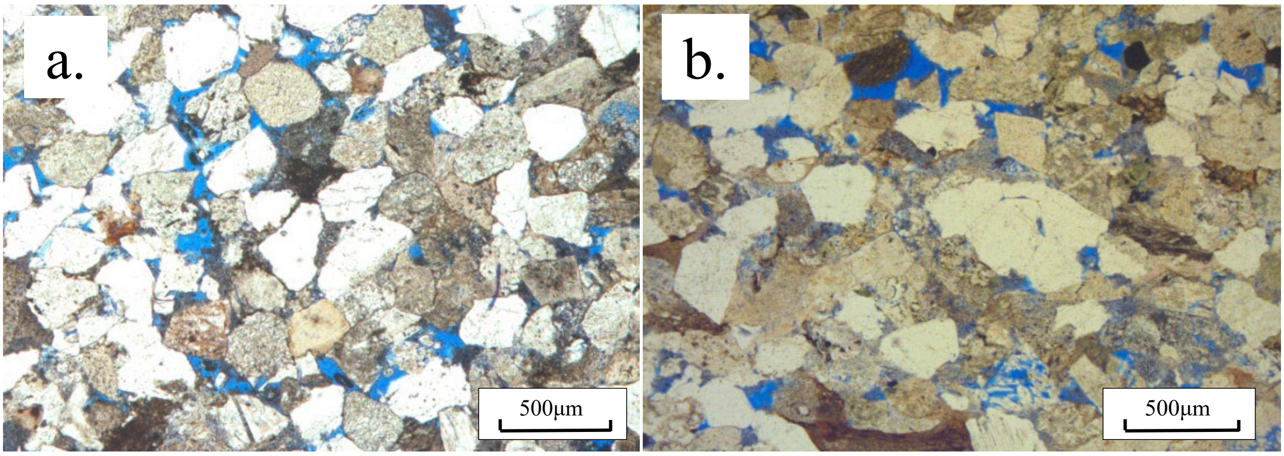

**Figure 15.** Observation of cast thin sections of the badawan formation reservoir (Dissolution) (a. MH Well 12, 2799.00 mm, $J_1b_1$, ×100, Matrix dissolved pores; b. MH Well 13, 3013.06 m, $J_1b_1$, ×100, particle dissolution pores).

The metasomatic effect is the process of material composition injection and escape, which is a replacement phenomenon that occurs after changes in temperature, pressure, and the chemical composition of the solution. The entire process of metasomatism occurs in the solid state with the participation of a solution; the decomposition of the original minerals and the formation of new minerals occur simultaneously. The alteration of the chemical composition of the original rock and the formation of various metasomatic textures in the newly formed rock are two significant characteristics of metasomatism. In the Badaowan Formation, the detrital grains that are metasomatized are mainly quartz, feldspar, and rock fragments, and the cement that is metasomatized is mainly the secondary enlargement rims of quartz, biotite, etc.

## 5. Conclusion

The rocks of the target layer in the study area are mainly lithic sandstone and feldspathic lithic sandstone. Among the cements, carbonate is dominant, followed by kaolinite and argillaceous materials. The main cementation type is pressure-embedded type, with pore-pressure-embedded type being the second. The reservoir is characterized by low porosity and extra-low permeability. Its reservoir space is mainly composed of intergranular pores and intragranular pores, and the proportion of structural fractures is relatively low.

The variation of reservoir physical properties is jointly controlled by sedimentation and diagenesis. Sedimentation lays the material foundation for the formation of the reservoir. The reservoir's physical properties are positively correlated with the sand content, and the distribution of sand bodies is determined by the distribution of sedimentary facies. Diagenesis plays a role in the later modification of the reservoir. Compaction is the main factor that destroys the primary pores. The pressure solution effect is not significant. The cementation is generally well-developed, and at the same time, metasomatism also occurs.

## Conflicts of Interest

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

## References

Chen, Y. B., Cheng, X. G., Zhang, H. et al. (2018). Fault Characteristics and Their Reservoir Control in the Middle and Shallow Layers of the Slope Area in the Mahu Sag. *Petroleum Exploration and Development, 45,* 985-994.

He, D. F., Zhang, L., Wu, S. T. et al. (2018). Tectonic Evolution Stages and Their Characteristics of the Junggar Basin. *Oil & Gas Geology, 39,* 845-861.

Hou, G. F., Wu, A. C., Zou, Z. W. et al. (2017). Sedimentary Characteristics and Models of Braided River Deltas in the Badaowan Formation of the Mahu Sag. *Xinjiang Petroleum Geology, 38,* 678-685.

Lei, H. Y., Guo, P., Meng, Y. et al. (2022). Pore Structure and Classification Evaluation of Shale Oil Reservoirs in Permian Fengcheng Formation of Mahu Sag. *Lithologic Reservoirs, 34,* 142-153.

Ma, W., Wei, Y., & Tao, S. (2018). A Method for Evaluating Paleo Hydrocarbon Pools and Predicting Secondary Reservoirs: A Case Study of the Sangonghe Formation in the Mosuowan Area, Junggar Basin. *Petroleum Science, 15,* 252-269.
https://doi.org/10.1007/s12182-018-0231-4

Meng, X. C., Chen, X. X., Dou, Y. et al. (2024). Differential Distribution, Origin of Oil and Gas Properties in Coal-Bearing Strata and Quantitative Prediction of Light Oil and Gas Accumulation Zones: A Case Study of the First Member of the Jurassic Badaowan Formation in the Slope Area of the Mahu Sag in the Junggar Basin. *Acta Sedimentologica Sinica*. https://link.cnki.net/doi/10.14027/j.issn.1000-0550.2024.044

Qian, Y. X., Zhao, Y., Liu, X. L. et al. (2025). Reservoir Characteristics and Main Controlling Factors of High-Yield Shale Oil in the Permian Fengcheng Formation of the Mahu Sag. *Lithologic Reservoirs, 37,* 115-125.

Qin, J. H., Wang, J. G., Li, S. Y. et al. (2023). Characteristics and Formation Mechanisms of Hydraulic Fractures in the Tight Conglomerate Reservoirs of the Triassic Baikouquan Formation in the Mahu Sag. *Lithologic Reservoirs, 35,* 29-36.

Song, M. (2020). Reservoir Formation Conditions and Key Technologies for Exploration and Development in Shengtuo Oilfield in Bohai Bay Basin. *Petroleum Research, 5,* 289-303. https://doi.org/10.1016/j.ptlrs.2020.08.003

Wang, L. S., Zhao, X. D., Li, L. et al. (2023). Reservoir Characteristics and Hydrocarbon Accumulation Control of Low Oil Saturation Reservoirs: A Case Study of the Badaowan Formation in the Middle and Shallow Layers of the Maxi Slope in the Junggar Basin. *Fault-Block Oil & Gas Field, 30,* 770-778.

Wu, X. Z., Liu, Z. X., & Wang, J. (2022). Potential, Distribution and Key Exploration Areas of Oil and Gas Resources in China. *Earth Science Frontiers, 29,* 146-155.