



Reservoir Characteristics and Main Controlling Factors of the Aershan Formation in the Shana Sag of the Erlian Basin

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ABSTRACT

The exploration and development of the Erlian Basin is long, and the Shana Sag located in the central part of the basin is a relatively underexplored new block, with little previous research conducted on this area. The Aershan Formation in this block has significant development potential. To achieve efficient development of the Aershan Formation oil reservoir in the Shana Sag, this article will combine previous data to study the petrological characteristics, pore throat characteristics, and physical properties of the reservoir rocks in the study area, and carry out favorable reservoir classification. The results indicate that the reservoir lithology of the Aershan Formation in the study area is primarily composed of pebbly, unevenly sized, fine to medium-grained sandstone, lithic sandstone and feldspathic lithic sandstone, with fillings mainly consisting of cement and argillaceous matrix. The average porosity of the reservoir is 14.5%, and the average permeability is 4.61 mD, making it a medium-porosity and extremely low-permeability reservoir. The pore types are primarily primary intergranular pores and dissolved intergranular pores, and the pore structure belongs to the small pore and medium-fine throat type. Based on characteristic parameters, the reservoir is divided into three categories; sedimentation and diagenesis play a crucial role in the formation of favorable reservoirs.

KEYWORDS

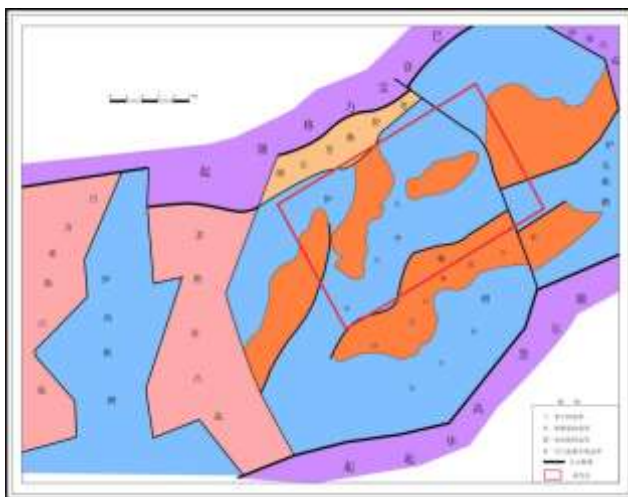
Shana Sag; Aershan Formation; Reservoir Characteristics; Diagenesis.

1. INTRODUCTION

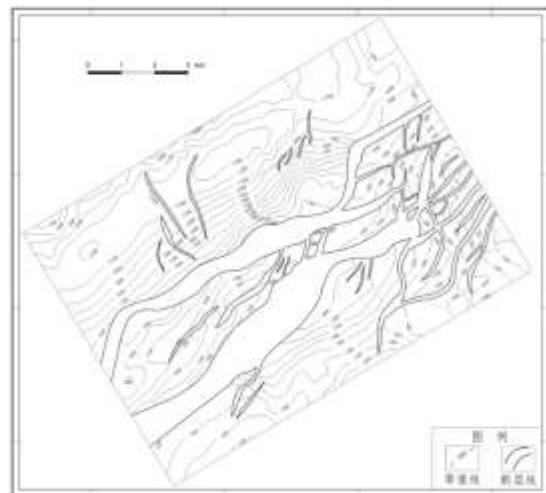
The Erlian Basin is located in the central part of Inner Mongolia Autonomous Region, extending from the Greater Khingan Range in the east to the Urad Middle-Rear Banner area in the west, bounded by the northern foothills of the Yin Mountains in the south and the China-Mongolia border in the north. It is a faulted lacustrine basin group dominated by the Lower Cretaceous, developed on the Hercynian folded basement of Inner Mongolia-Greater Khingan Range, with a geological structure belonging to the passive rift basin type. Regional exploration and development have a long history, having gone through five stages: geological survey, comprehensive exploration, structural reservoir exploration, stratigraphic-lithologic reservoir exploration breakthrough, and new sag exploration. Currently, oil and gas extraction has transitioned from a strategic phase to a stable development phase [1-6]. The Shana Sag, located in the central-northern part of the Manite Depression in the Erlian Basin, has favorable exploration prospects. The geological conditions in this area are conducive to the formation of good lithologic reservoirs. However, the understanding of the development of the Shana Sag is relatively low. This article will refer to previous studies to improve the analysis of reservoir characteristics of the Aershan Formation in the Shana Sag, further deepen the understanding of the Shana Sag, and provide a theoretical basis for subsequent development work in this area.

2. REGIONAL GEOLOGICAL OVERVIEW

The Shana Sag covers an area of approximately 800 km², with a depth of about 3250 m, and a length-to-width ratio of about 3:1. It can be further divided into the Yidong Fault Trough and Yizhong Fault Trough[7]. This study focuses mainly on the Yizhong Fault Trough (Figure 1a). The Lower Cretaceous in this area has a complete sedimentary cycle from coarse to fine to coarse, which can be divided into four series of normal and reverse cycles. The region experienced sedimentary tectonic events at the end of the Jurassic, the end of the deposition of the fourth member of the Aershan Formation, the end of the deposition of the first member of the Tengger Formation, the end of the deposition of the second member of the Tengger Formation, and the end of the deposition of the Saihantala Formation, forming five major regional unconformities and sedimentary discontinuities[8-11]. The study area is located in the central-northern part of the Shana Sag, which is a fault-block structure complicated by faults. The main fault trend is consistent with the regional structural trend, but locally influenced by tectonic stress, the fault trend turns to north-northeast. The faults have large throws, long extensions, and cut through multiple strata. They play three main roles in the sag: controlling the structural framework, controlling sedimentary deposition, and connecting hydrocarbon sources. These faults are the main oil-source faults in the study area. Hydrocarbons migrate downward through the main faults and laterally along unconformities, accumulating in favorable traps above. Secondary faults in the north-south direction are smaller in scale, with smaller throws and shorter extensions. They intersect with the main faults, complicating the structure and mainly controlling the distribution of oil and gas in this area. During the deposition of the Aershan Formation, the northern sub-sag of the Yizhong Fault Trough in the Shana Sag was a lacustrine facies. Intense fault activity caused significant changes in stratum thickness. Influenced by meltwater from the Bayanbaolige uplift area, rivers provided water sources for the lake, forming a faulted lacustrine basin-type fan delta deposit. From bottom to top, the scale of the fan delta gradually expanded[12-14]. The area accumulated variegated coarse clastic rocks, which rapidly transitioned to deep lacustrine gray mudstone toward the center of the lake basin, locally interbedded with thin layers of marl or dolomitic mudstone. The fan delta is composed of coarse-grained conglomerate and sandstone with poor sorting but good reservoir physical properties[15]. Based on the above factors, the area is considered to have favorable development prospects.



a. Structural unit division map of the Shana Sag



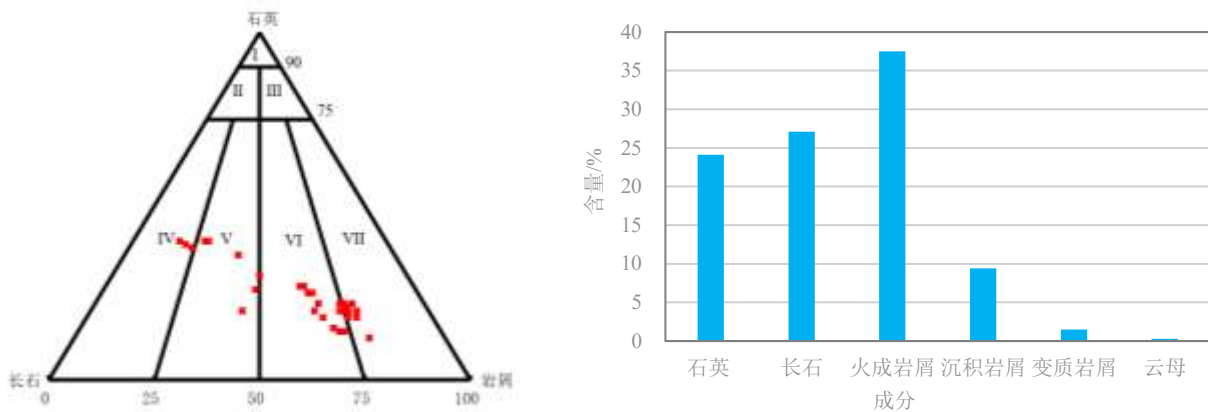
b. Top structure map of the fourth member of the Aershan Formation in the study area

Figure 1. Structural unit division map of the Shana Sag and top structure map of the fourth member of the Aershan Formation in the study area

3. RESERVOIR CHARACTERISTICS

3.1. Reservoir Petrological Characteristics

Core observations and cast thin section identification data indicate that the reservoir lithology of the Aershan Formation in the study area is mainly composed of pebbly, unevenly sized, fine to medium-grained lithic sandstone and feldspathic lithic sandstone, followed by feldspathic sandstone and lithic feldspathic sandstone. The content of terrigenous clastic components ranges from 70% to 96%, with an average of 84.4%. The average contents of quartz, feldspar, igneous rock fragments, sedimentary rock fragments, and metamorphic rock fragments are 24.1%, 27.1%, 37.5%, 9.4%, and 1.5%, respectively. The gravel components in sandy conglomerate are mainly rhyolite, tuff, sedimentary tuff, granite, etc., with an average gravel content of 78%.



a. Sandstone composition of the Aershan Formation reservoir

b. Statistical diagram of sandstone clastic composition of the Aershan Formation

Figure 2. Classification of sandstone composition of the Aershan Formation reservoir in the study area

The interstitial materials in the study area are mainly cement and argillaceous matrix. The cement includes volcanic ash, clay minerals, and carbonate cement. The average content of volcanic ash is 9.8%. Clay minerals include kaolinite, illite, and chlorite, accounting for 1.16%, 1.00%, and 1.13%, respectively. Carbonate cement is mainly composed of calcite and ferrocalcite, accounting for 1.84% and 1.93%, respectively. Dolomite and ferrodolomite are locally observed, accounting for 2.10% and 1.31%, respectively. Silica and pyrite are only visible in some samples, accounting for 1.00% and 1.50%, respectively (Figure 3).

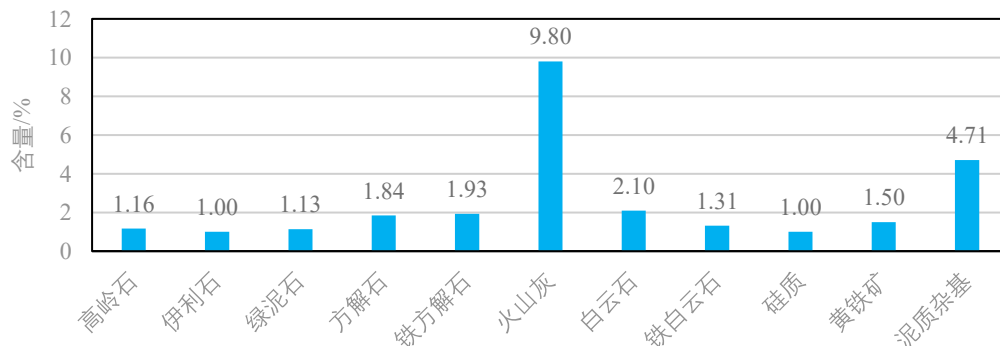
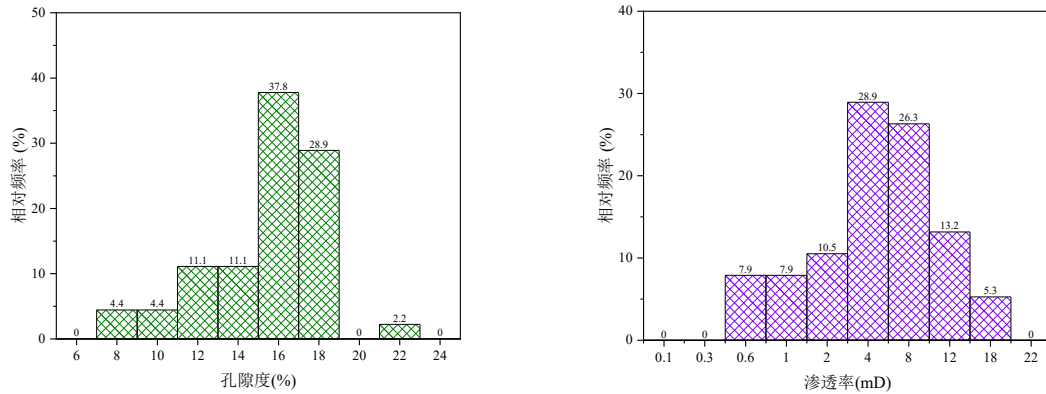


Figure 3. Types of interstitial materials in the tight sandstone of the Aershan Formation

3.2. Reservoir Physical Properties

According to conventional analysis data of core samples from the study interval in the study area, the reservoir porosity ranges from 8.0% to 20.7%, with an average of 14.5% and a median of 15.1%. The reservoir permeability ranges from 0.49 mD to 15.11 mD, with an average of 4.61 mD and a median of 3.81 mD. Therefore, the Aershan Formation reservoir in the study area is classified as a medium-porosity and extremely low-permeability reservoir.

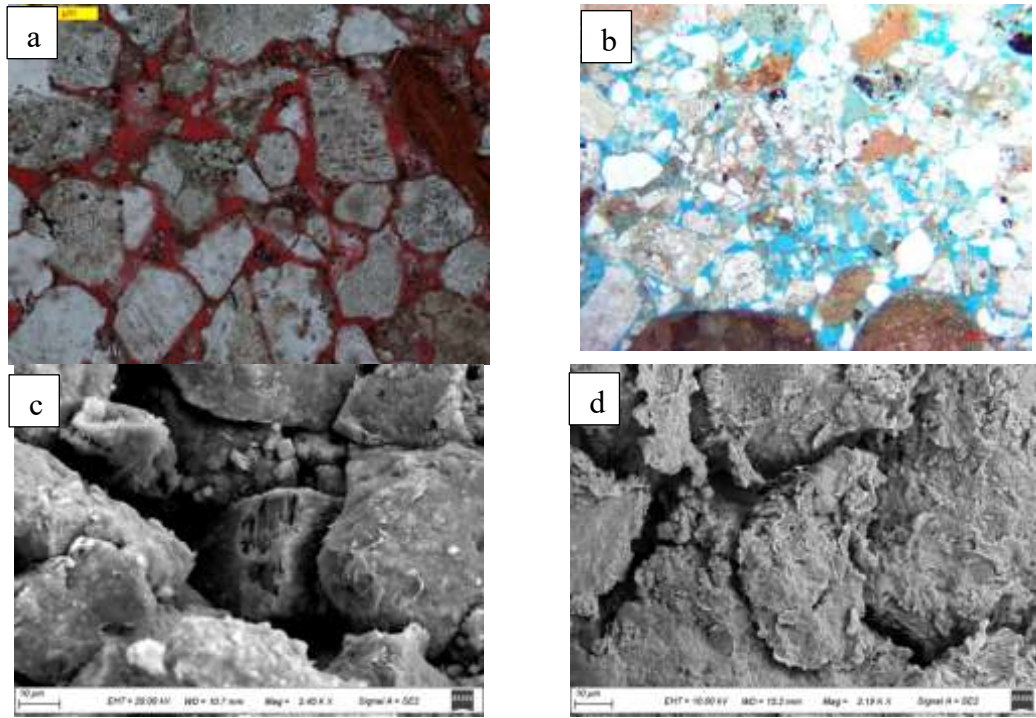


a. Histogram of reservoir porosity in the study area b. Histogram of reservoir permeability in the study area

Figure 4. Histograms of porosity and permeability distribution of the fourth member of the Aershan Formation reservoir in the study area

3.3. Pore Throat Characteristic

Through cast thin sections and scanning electron microscopy observations (Figure 5), the pore development in the Aershan Formation reservoir in the study area varies significantly. The surface porosity ranges from 0.5% to 24.5%, with an average of 6.1%. The main pore types include primary intergranular pores (28.5%), dissolved intergranular pores (25.8%), and microfractures (18.5%). The remaining types include feldspar dissolution pores, clastic dissolution pores, intercrystalline dissolution pores, and micropores.



a. Well-connected intergranular pores b. Mainly intergranular pores and intergranular dissolution pores, with a small number of feldspar dissolution pores c. Residual intergranular pores, clastic particle dissolution pores d. Residual intergranular pores

Figure 5. Microscopic photos of pore types in the Aershan Formation reservoir

High-pressure mercury injection experiments were used to obtain capillary pressure curves, analyzing the size, distribution, and connectivity of the pore structure. The parameters from the mercury injection experiments for the Aershan Formation reservoir in the study area are as follows (Table 1). Combined with scanning electron microscopy images, the pore diameter in the Aershan Formation reservoir ranges from 0 to 400 μm , with an average of 41.07 μm , belonging to the small pore and medium-fine throat type.

Table 1. High-pressure mercury injection parameters of the Aershan Formation pores

Layer	Parameter	Median Pressure (MPa)	Median Radius (μm)	Displacement Pressure (MPa)	Average Pore Throat Radius (μm)	Maximum Connected Pore Throat Radius (μm)	Mercury Withdrawal Efficiency (%)	Sorting Coefficient
Aershan Formation	Maximum	43.37	7.357	23.99	4.73	36.73	61.31	8.55
	Minimum	0.10	0.017	0.02	0.058	0.031	27.78	0.02
	Average	25.56	0.75	42.98	1.35	4.02	31.36	2.56

By comprehensively considering porosity, permeability, effective thickness, and capillary pressure as the main characteristic parameters, the reservoir in the study area was classified and evaluated [16,17], and the Aershan Formation reservoir in the study area was divided into three categories.

Table 2 Classification and evaluation table of the Aershan Formation reservoir in the study area

Classification Parameters	Sedimentary Microfacies	Physical Properties		Capillary Pressure Characteristic Parameters					Reservoir Evaluation	
		Porosity(%)	Permeability(mD)	Displacement Pressure(MPa)	Median Pressure(MPa)	Average Pore Throat Radius(μ m)	Median Radius(μ m)	Sorting Coefficient		
Reservoir Classification	I	Main Subaqueous Distributary Channel	≥ 15	5.0-1.0	0.02-8.2	0.1-22	4.72-1.48	7.36-0.036	4.68-3.3	Better Reservoir
	II	Subaqueous Distributary Channel	15-10	1.0-0.3	8.2-14	22-37	1.48-0.236	0.036-0.02	3.3-0.27	Medium Reservoir
	III	Subaqueous Distributary Channel Flank	10-5	0.3-0.1	14-23.99	37-43.37	0.236-0.058	0.02-0.017	0.27-0.09	Poor Reservoir

Class I reservoirs are widely distributed in the study area, mainly in the main subaqueous distributary channels, with well-developed sand bodies. They have higher porosity, permeability, average pore throat radius, median radius, and sorting coefficient, with lower displacement pressure and median pressure, resulting in good reservoir properties and connectivity.

Class II reservoirs are also widely distributed in the study area, mainly developed in subaqueous distributary channels, with medium-quality sand bodies. The well-developed chlorite films and feldspar dissolution pores improve the reservoir storage capacity. The physical properties and capillary pressure characteristic parameters fall within the median range, indicating general reservoir properties and connectivity.

Class III reservoirs are less distributed in the study area, mainly developed on the flanks of subaqueous distributary channels. The sand bodies are relatively thin, with higher displacement pressure and median pressure, indicating poor reservoir quality. Additionally, the development of secondary pores occupies reservoir space, leading to low values of porosity, permeability, average pore throat radius, median radius, and sorting coefficient. They are classified as microporous-microthroat pore types, with very poor reservoir properties and connectivity.

4. MAIN CONTROLLING FACTORS OF RESERVOIR QUALITY

4.1. Sedimentation

The sedimentary facies of the Aershan Formation in the study area is a fan delta facies, further divided into three subfacies and five microfacies. Among them, the subaqueous distributary channels and subaqueous distributary bays of the fan delta front are the main microfacies, with subaqueous distributary channel sand bodies as the main reservoir units. The microfacies of the delta plain are distributary channels and interdistributary areas, while the prodelta microfacies are prodelta mud. From the sedimentary facies plane map (Figure 6), it can be seen that from bottom to top, the fan delta lobes of the Aershan Formation in the study area gradually expanded to the north-northeast, reflecting a regression process. Three subaqueous distributary channel sand bodies are developed, with the middle subaqueous distributary channel sand body being the most developed, providing favorable sites for oil and gas accumulation.

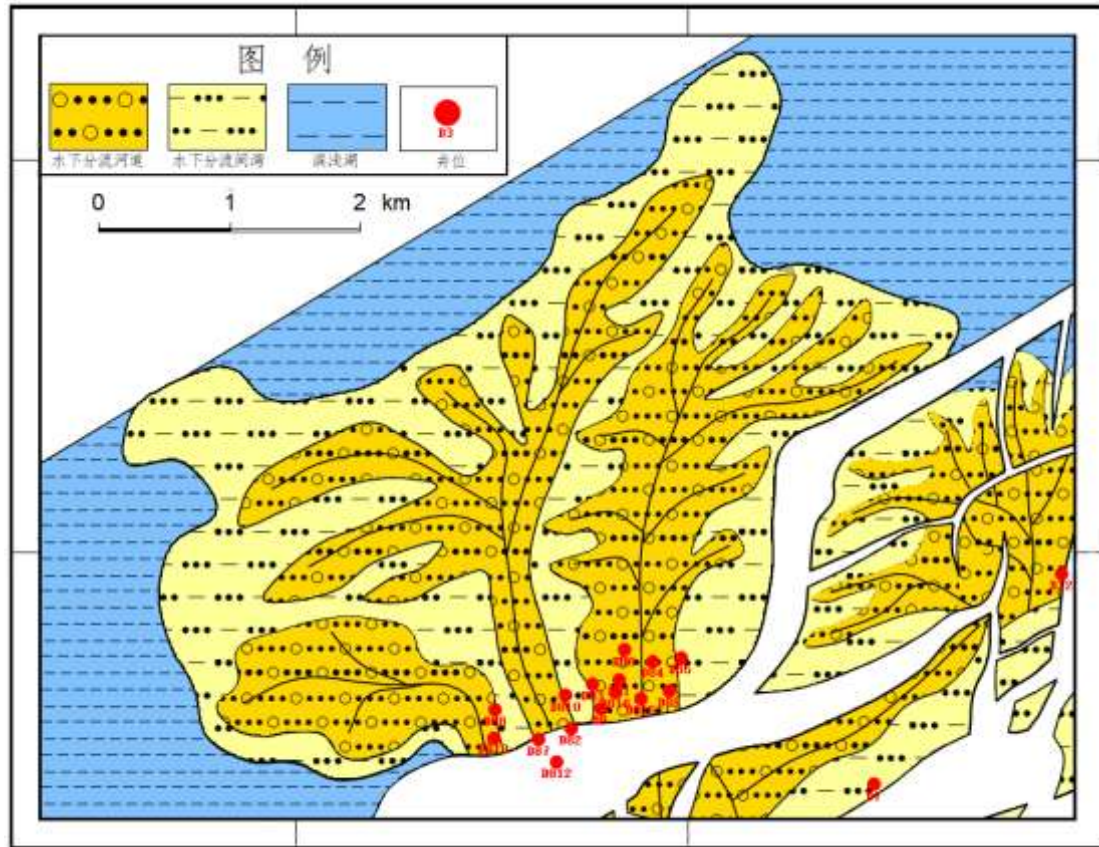
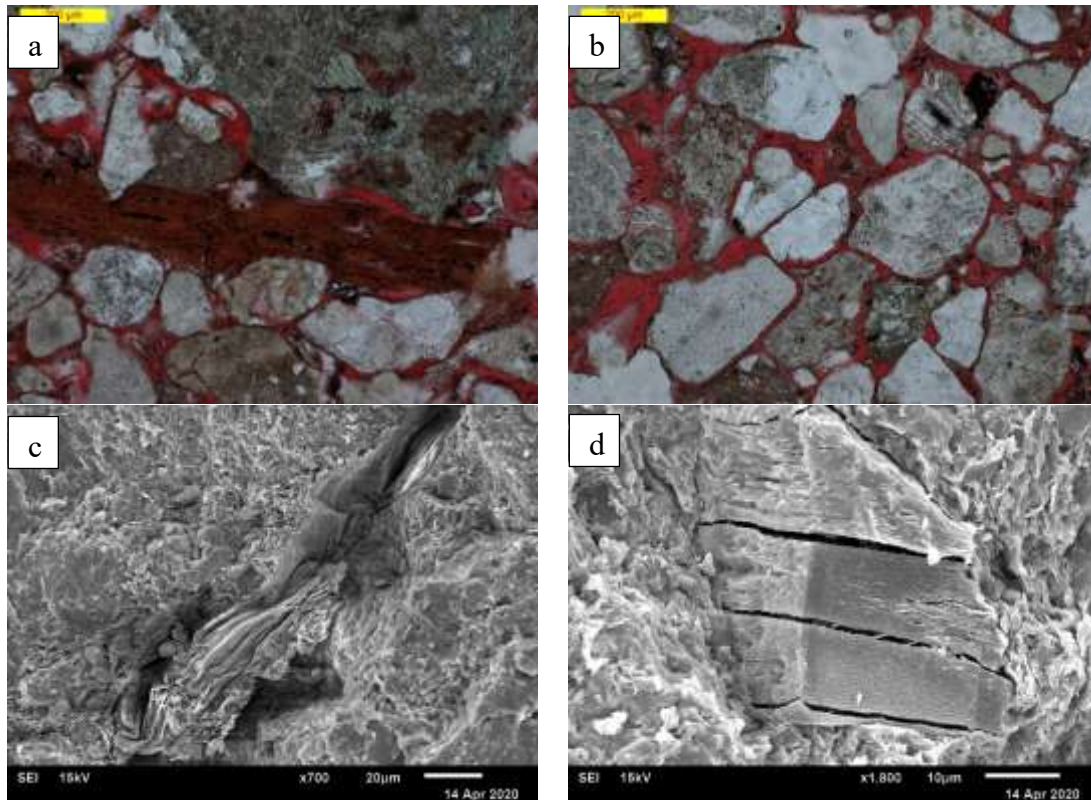


Figure 6. Sedimentary facies plane map of the fourth member of the Aershan Formation in the study area

The medium-thick fine to medium sandstone reservoir of the Aershan Formation in the Shana Sag is in unconformable contact with the overlying Tengger Formation. The middle-lower part of the first member of the Tengger Formation and the middle-lower part of the second member of the Tengger Formation widely develop semi-deep to deep lacustrine dark mudstone. The source rocks of the first member of the Tengger Formation have high organic matter abundance, with organic matter types mainly III~II2, belonging to good source rocks. The oil and gas have reached maturity and are generating in large quantities, making the first member of the Tengger Formation the main oil-generating layer. The source rocks of the second member of the Tengger Formation have high organic matter abundance, with organic matter types mainly II2, belonging to good source rocks. However, due to shallow burial, most of the oil and gas have not yet been generated, so it is not the main oil-generating layer [18]. The medium-thick fine to medium sandstone reservoir of the Aershan Formation in the Shana Sag and the overlying dark gray mudstone of the first member of the Tengger Formation constitute the main reservoir-cap rock combination in this area, playing a key role in the accumulation of oil and gas.

resulting in low surface porosity. The contact modes between particles are mainly linear and point-linear contacts, with long-axis directional arrangement (Figure 8 b).



a. Mica deformation, well-preserved, weak deformation b. Quartz rigid particles, cracked under compression, arranged in long-axis direction c. Mica fragments d. Intragranular fractures

Figure 8. Compaction of the Aershan Formation reservoir

4.2.2. Cementation

The cementation in the Aershan Formation in the study area is mainly carbonate cementation, quartz and feldspar overgrowth cementation, and authigenic clay cementation.

(1) Carbonate Cementation

The carbonate cements in the study area are mainly calcite and ferrocalcite, filling pores as continuous crystals, and partially as granular cement (Figure 9 a-d).

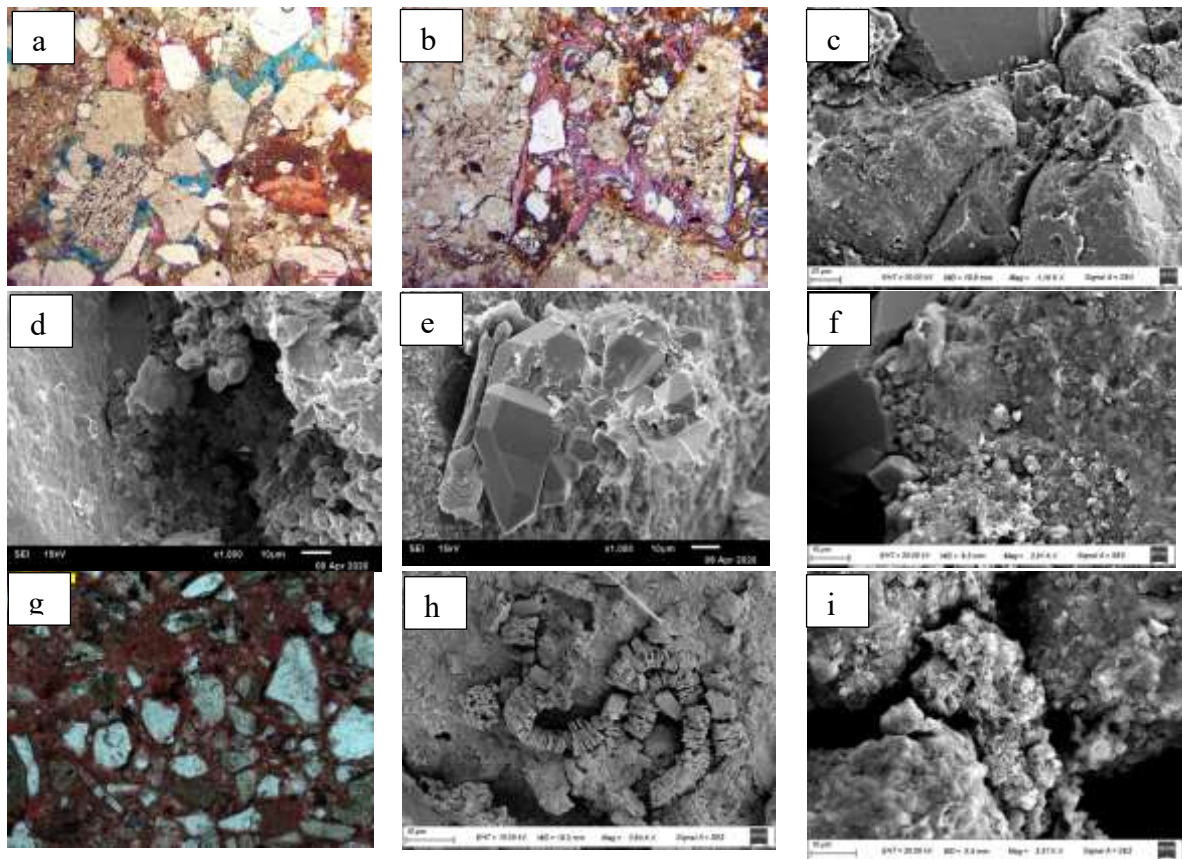
(2) Authigenic Quartz and Feldspar Overgrowth

In the Aershan Formation sandstone reservoir in the study area, quartz overgrowth cementation is common, while feldspar overgrowth is less common, appearing as microcrystals. The content of quartz and feldspar cements is relatively low, generally less than 1%. Under scanning electron microscopy, authigenic quartz mostly appears as single crystals filling intergranular pores, with well-developed hexagonal pyramidal authigenic quartz filling intergranular pores. The crystals are complete, clean, and have clear edges (Figure 9 e). Quartz overgrowth edges (Figure 9 f) rarely appear as rim-like structures. On one hand, they occupy pore space, causing some damage to the reservoir space; on the other hand, they enhance the compressive resistance of the reservoir, providing favorable material conditions for the dissolution of siliceous cements by alkaline fluids in the late stage.

(3) Authigenic Clay Mineral Cementation

The formation of chlorite coatings in the early diagenetic stage A and the precipitation of illite-smectite mixed layers and the transformation of illite in the early diagenetic stage B are common in

the fourth member of the Aershan Formation reservoir in the study area (Figure 9 g-i). The main occurrence of chlorite in sandstone is as clay coatings lining pores, often with blade-like chlorite distributed perpendicular to the surface of clastic particles, forming a comb-like structure [19,20]. Illite-smectite mixed layers often appear as particle coatings or pore linings, with curled sheet-like crystal forms. The formation of chlorite coatings reduces pore throat radius while significantly inhibiting compaction and pressure dissolution, generating a large number of micropores, complicating the pore structure, protecting primary pores, and improving reservoir physical properties. Illite-smectite mixed layers transform intergranular pores into intercrystalline pores, reducing reservoir porosity and permeability.

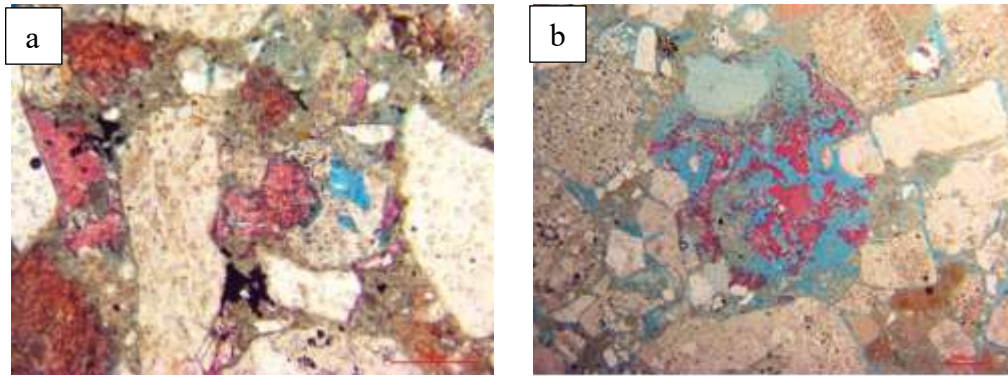


a. Intergranular dissolution pores and calcite cementation b. Calcite and ferrocalcite cementation c. Calcite cementation d. Secondary quartz, granular calcite, intergranular pores e. Hexagonal pyramidal authigenic quartz f. Quartz overgrowth and clay minerals such as chlorite as grain-coating linings g. Abundant clay minerals filling pores h. Grain-coating kaolinite, illite-smectite mixed layers, and other clay minerals, along with spherical pyrite i. Grain-coating chlorite and other clay minerals, along with residual intergranular pores

Figure 9. Cementation of the Aershan Formation reservoir

4.2.3. Metasomatism

Metasomatism can alter the rock structure, leading to changes in porosity and permeability. In the Aershan Formation reservoir in the study area, metasomatism is mainly calcite and ferrocalcite replacing clastic particles. Under cathodoluminescence, clear residual structural features of calcite replacement can be observed (Figure 10 a, b).

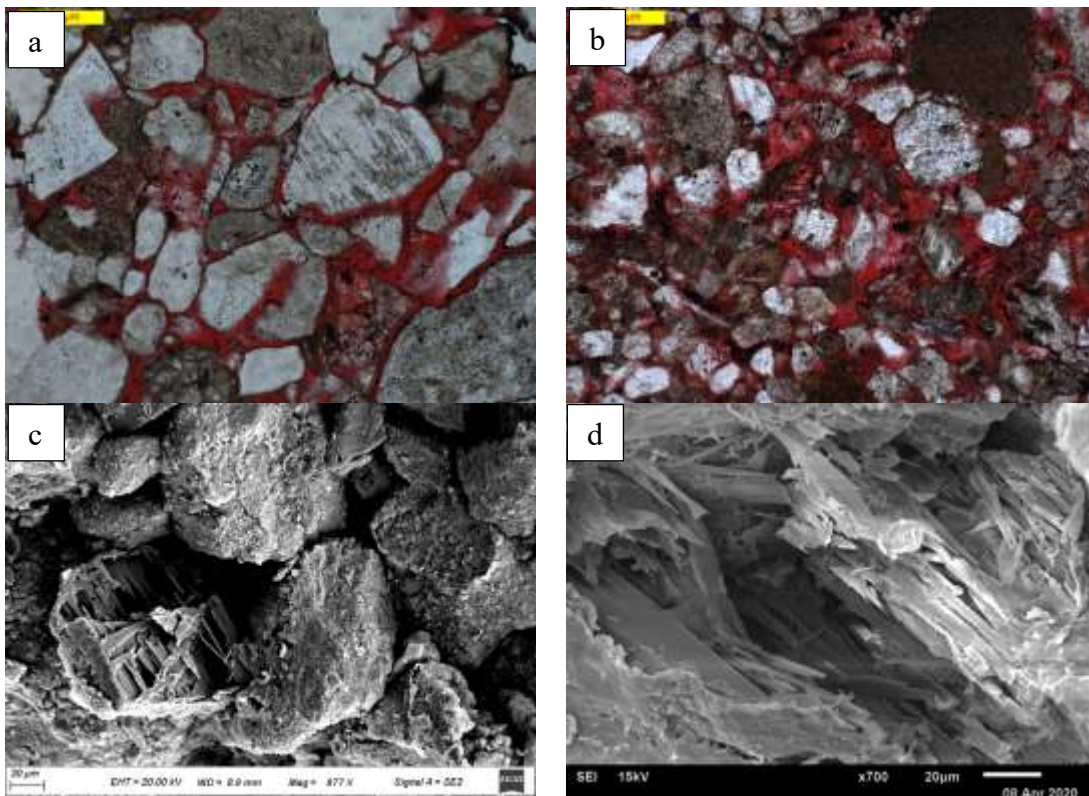


a. Calcite and ferrocalcite replacing clastic particles b. Calcite replacing clastic particles and intergranular dissolution pores

Figure 10. Metasomatism of the Aershan Formation reservoir

4.2.4. Dissolution

Strong dissolution occurred in the Aershan Formation reservoir in the study area during the middle diagenetic stage A, forming a large number of dissolution-type secondary pores. These mainly include lithic dissolution pores, feldspar dissolution pores formed by leaching of feldspar and other lithic particles, and dissolution of matrix and authigenic clays. Dissolution effectively improved reservoir physical properties by forming a large number of secondary pores (Figure 11 a-d).



a. Intergranular pores and feldspar dissolution pores b. Well-developed intergranular pores and dissolution pores, with good pore connectivity c. Residual intergranular pores, clastic particle dissolution pores d. Intragranular dissolution pores of feldspar

Figure 11. Dissolution of the Aershan Formation reservoir

5. PREDICTION OF FAVORABLE RESERVOIR DISTRIBUTION

The Aershan Formation reservoir in the study area is located in a structural high, forming a faulted anticlinal reservoir. The provenance direction is from south to north, controlled by both lithology and

structure, belonging to a lithologic-structural reservoir. From a sedimentary perspective, Class I and II reservoirs are located in the main development areas of subaqueous distributary channels, while Class III reservoirs are in poorly developed subaqueous distributary bays. From a physical property perspective, the sand bodies of high-quality subaqueous distributary channels have relatively good physical properties. However, influenced by compaction, the physical properties of local subaqueous distributary channels deteriorate, and the sand bodies become tight, turning into dry layers or tight layers. Oil and gas barriers appear in the updip and lateral directions of the sand layers. At the same time, the physical properties of subaqueous distributary bays deteriorate, with thinner sand layers, increased clay content, and severe pore throat blockage, leading to lateral barriers and reduced reservoir quality. Attention should be focused on the well-developed sand bodies of subaqueous distributary channels.

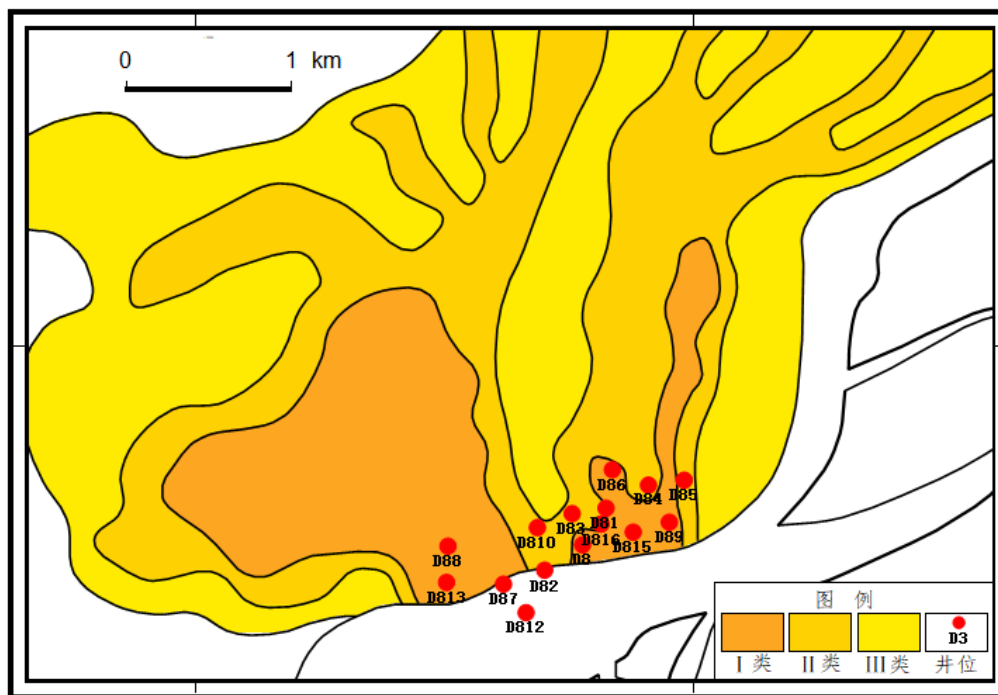


Figure 12. Plane distribution map of different types of reservoirs in the Aershan Formation in the study area

6. CONCLUSIONS

(1) The reservoir lithology of the Aershan Formation in the study area is mainly composed of pebbly, unevenly sized, fine to medium-grained lithic sandstone and feldspathic lithic sandstone. The interstitial materials mainly include volcanic ash, clay minerals, carbonate cement, and argillaceous matrix. The main pore types are primary intergranular pores and dissolved intergranular pores. The average porosity is 14.5%, and the average permeability is 4.61 mD, belonging to a medium-porosity and extremely low-permeability reservoir.

(2) The favorable reservoir sedimentary facies in the Aershan Formation in the study area are mainly subaqueous distributary channels. The overlying mudstone of the first member of the Tengger Formation provides a favorable formation environment for the reservoir. Diagenetic compaction densifies intergranular pores, with contact modes mainly linear and point-linear contacts. Cementation reduces pore throat radius while enhancing the compressive resistance of the reservoir and generating microfractures. Metasomatism and dissolution effectively improve reservoir physical properties.

(3) The study area belongs to a lithologic-structural reservoir. Based on comprehensive reservoir characteristic parameters and the planar distribution of sedimentary facies, the reservoirs in the study area are divided into three categories, with Class I and II reservoirs of better quality mainly located in the main parts of subaqueous distributary channels.

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