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Reservoir Quality and Its Control Factors of Complex Fault Block Reservoir in Continental Faulted Basin, Case Study in the Wang Guantun Area, Bohai Bay Basin, China

Bin Zhao [1,2], Wei Han [1,3,*], Tingjian Ma [1,2], Gang Gao [1,2] and Ling Ji [4]

1 Key Laboratory of Exploration Technologies for Oil and Gas Resources, Ministry of Education, Yangtze University, Wuhan 434025, China
2 College of Geophysics and Petroleum Resources, Yangtze University, Wuhan 434025, China
3 School of Geosciences, Yangtze University, Wuhan 434025, China
4 PetroChina Dagang Oilfield Company, Tianjin 300000, China
* Correspondence: hanxiaoka330@163.com; Tel.: +86-13114642330

Abstract: Continental faulted basins are widely distributed in eastern China. Many of these basins, in which the faults block oil and gas reservoirs, have been explored. The heterogeneity of the reservoirs in fault block is very strong, shich restricts the further efficient development of these kinds of oil and gas fields. In this study, porosity and permeability tests, the use of thin sections of rock, mercury injection experiment and CT scan were used to investigate reservoir quality characteristics and control factors. The results showed that the content of quartz, feldspar, and debris in rock had a significant control function on the quality of the reservoir. Reservoir performance improved with increase of quartz and feldspar content, and worsened with increase of debris content. Taking the Ek1 reservoir in the Wang Guantun area as the specific research object, we developed the following understanding. On the one hand, the main compaction in the study area was mechanical compaction. When the compaction rate was greater than 60%, the porosity and permeability were inversely proportional to the compaction rate. On the other hand, dissolution pores were relatively developed in the study area, and the main types of dissolution were intragranular and intergranular dissolution pores. When the surface porosity of the dissolution pore was over 9.2%, porosity increased significantly the increase of dissolution surface porosity. This showed that dissolution surface porosity had greatly improved the reservoir porosity in this range.

Keywords: Bohai bay basin; complex fault block oilfield; reservoir quality; sedimentary components; diagenesis

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1. Introduction

There are many faulted basins in eastern China, where hydrocarbon easily accumulatess and forms fault block oilfields. Fault block oilfields have many characteristics, such as a large number of faults, diverse forms, a complex oil-water system, and inconsistent oil-water interface, which makes their exploration and development difficult [1,2]. Predecessors have done a lot of research on the structural characteristics, sand body distribution characteristics, and oil–water distribution characteristics of complex fault block oilfields. The main research methods include seismic fine interpretation method, artificial intelligence attribute fusion and well seismic combined sedimentary interpretation. At present, scholars around the world have made rich research achievements in the study of the spatial distribution of reservoir heterogeneity [3–5].

In continental faulted basins, the frequent changes of sedimentary facies lead to strong heterogeneity of reservoirs, and the influence of fault make the reservoir spaces more complex [6,7]. In the Wang Guantun area of Huanghua Depression, Bohai bay basin, multilevel faults have developed in the reservoirs. Faults cut the stratum into several small fault blocks, and hydrocarbon accumulates to form oil and gas reservoirs when encountering appropriate fault traps in the process of migration [8]. Previous studies have clarified the tectonic evolution, provenance characteristics and sedimentary evolution of the Wang Guantun area. The controlling effect of synsedimentary faults on the development of reservoir dissolution pores, the controlling effect of synsedimentary faults on hydrocarbon accumulation and the accumulation model have also been studied [9–13].

In this study, we used the physical property test, mercury intrusion test, scanning electron microscope, X-ray diffraction (XRD) test and other methods to clarify the general characteristics of reservoir quality in the Wang Guantun area, and further investigated the control of sedimentation, diagenesis and tectonism on reservoir quality. The research shows that sedimentary fabric, intersection and dissolution have obvious control over reservoir quality. In complex fault block reservoirs, the late reformation of synsedimentary faults is also an important factor that cannot be ignored.

2. Geological Setting

The Huanghua Depression is located in the north–central part of the Bohai bay basin, and belongs to the Cenozoic fault-depression basin. Its northern boundary is Yanshan fold system, its west is bound by Cangxian uplift and is adjacent to Jizhong sag, its southeast is bound by chengning uplift and adjacent to Jiyang sag, and its northeast extends to Bohai Sea area and is adjacent to Haizhong uplift. It is distributed along the northeast–southwest direction, with a long axis of about 260 km and a short axis of 20~100 km [14]. On the plane, it is narrow in the south and wide in the north, showing a triangular shape. Longitudinally, it is slightly shallow in the southeast and steep and deep in the northwest, with a total area of about 17,000 km^2, including a land area of about 12,000 km^2 (Figure 1). Kongnan area is a continuous depression area south of Kongdian uplift in Huanghua depression. Kongdian buried hill structural belt is an important hydrocarbon-bearing structure in the Kongnan area. The study area, the Wang Guantun area, is located on both sides of the Kongdian structural belt, with a total area of about 140 km^2.

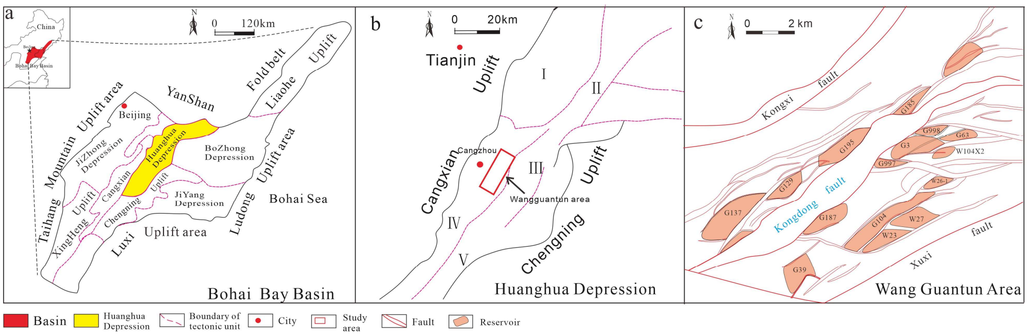


Figure 1. The geographical and structural maps of the Wang Guantun Area. (**a**) Bohai Bay Basin; (**b**) Huanghua Depression; (**c**) Wang Guantun area.

The strata in the Wang Guantun area belong to Mesozoic, Paleogene Kongdian formation, Shahejie formation, Neogene Guantao formation, Minghuazhen Formation and Pingyuan formation, respectively, from bottom to top, of which the number of wells drilled into Mesozoic strata is small (Figure 2). The Kongdian Formation is divided into Ek3, Ek2 and Ek1 members from bottom to top, and Shahejie Formation is divided into Es3, Es2 and Es1 members. The stratum of Ek1 member is relatively thick and mainly develops sand-mudstone interbeds, which can be divided into 6 oil groups. They are Z0, ZI, ZII, ZIII, ZIV, and ZV oil groups, from top to bottom, respectively. The oil groups from ZII to ZV are the main oil-bearing layers of Ek1 in the Wang Guantun area. Further, the ZII can be divided into 5 sublayers and 15 single layers. The ZIII can be divided into 4 sublayers and 16 single layers. The ZIV can be divided into 11 sublayers and 54 single layers. The ZV can be divided into 7 sublayers and 22 single layers (Figure 2).

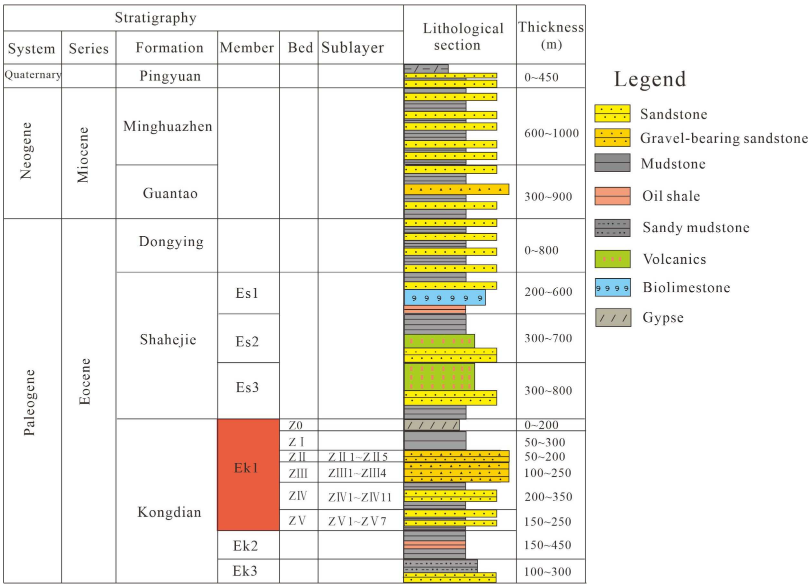


Figure 2. The chrono and lithostratigraphical column of the Wang Guantun Area.

During the deposition of the Kongdian Formation, the tectonic movement in the entire Kongnan area was intense, and the periphery of the sag was gradually uplifted. Therefore, the Chengning uplift in the east, the Cangxian uplift in the west and the Kongdian uplift in the north formed gradually. During the sedimentary period of Ek1 member, the climate was arid, and the lake water evaporated. A set of red clastic rocks intercalated with an evaporite formation sequence was deposited. The sedimentary system of Ek1 member in the Wang Guantun area was mainly developed as an alluvial fan-fan delta depositional system, in which the alluvial fan is dominated by the middle fan sub-facies, and the fan delta is mainly the sub-facies in the front of the fan delta. The middle fan sub-facies can be divided into three types of sedimentary microfacies: braided channel, channel bar, and interchannel, and the front of the fan delta can be divided into four types of sedimentary microfacies: subaquatic distributary channel, river mouth bar, sheet sand, and interchannel.

3. Data and Experimental Method

In this study, a total of 602 porosity and permeability data were used, which were collected from PetroChina Dagang Oilfield Company. During core observation, a large number of rock samples from different layers were collected, and the samples were divided into several parts, which were made into thin sections and cubes to complete the analysis of rock thin sections, scanning electron microscopy (SEM), and mercury injection experiment.

The principle of analysis of rock thin sections is to identify the composition differences in rocks by observing the light passing through the rock slice through the microscope. In the experiment, the rock samples need to be cut into thin sections less than 30 microns, so that the light can pass through it. This process mainly includes cutting, smoothing, gluing, slicing, grinding and polishing.

Scanning electron microscopy (SEM) is an experimental method for observing rock samples by electron microscopy to obtain their pore types and diagenetic characteristics [15–17]. In this experiment, the rock samples were treated to 3 mm, and the samples were ground with LaboPol-21 Polishing and Silicon carbide papers to make them smooth enough. Finally, a Hitachi S4800 electron microscope (resolution and accelerating voltage were 1.2 nm and 30 kV) was used to observe the rock samples.

Based on the data of the mercury injection curve, mercury withdrawal curve, and pore size distribution obtained from the mercury injection experiment, we can study the pore structure characteristics of rocks. In this paper, PoreMaster-9500 mercury porosimeter (maximum pressure can reach 200 MPa, and the minimum pore size can be measured by 3.6 nm) was used for mercury injection experiments.

4. Results

4.1. Petrological Characteristics

Rock slice identification of the 1336 samples from the 192 wells in the Wang Guantun area showed that the content of feldspar and rock debris was widely distributed and the rock composition maturity in each formation was about 0.35~2.31, and the average value was 1.0 (Table 1). The composition of rock cuttings in Ek1 member in the Wang Guantun area was quite different. In each layer of the rising wall of Kongdong fault, the contents of sedimentary rocks, metamorphic rocks and igneous rocks were similar, 30~35%. While the content of igneous rock cuttings in all layers of the descending wall of Kongdong fault was high, accounting for about 65% of the total cuttings, the content of sedimentary rock cuttings and metamorphic rock cuttings were about 16.5%.

Table 1. Detrital composition of Ek1 member in the Wang Guantun Area.

Beds	Quartz Content/%			Feldspar Content/%			Rock Fragment Content/%			Composition Maturity		
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
ZII	11.5	64.3	36.7	9.7	55.6	24.5	6.95	41.6	38.2	0.35	1.95	0.87
ZIII	11.6	72.3	38.5	9.2	49.8	23.8	7.71	40.1	36.5	0.41	1.97	0.92
ZIV	14.5	68.4	42.5	10.8	38.6	26.4	5.5	43.4	29.3	0.54	2.25	1.08
ZV	15.3	70.2	44.1	11.6	53.2	25.6	4.3	40.2	28.4	0.55	2.31	1.14

The composition maturity calculation method is: $\frac{Quartz\ content}{feldspar\ content + debris\ content}$.

According to the core observation, the lithology of Ek1 member in the Wang Guantun area mainly included pebbly sandstone, coarse sandstone, medium fine sandstone, siltstone, argillaceous siltstone and mudstone (Figure 3). The sandstone of Ek1 member in the Wang Guantun area mainly included arkose, lithic arkose, lithic arkose and feldspathic lithic sandstone. For arkose, the quartz content was less than 75% and the ratio of feldspar to rock fragment (F/R) was greater than 3. For lithic arkose, the quartz content was more than 75% and 1 < F/R < 3. For feldspathic lithic sandstone, the quartz content was more than 75% and 1/3 < F/R < 1.

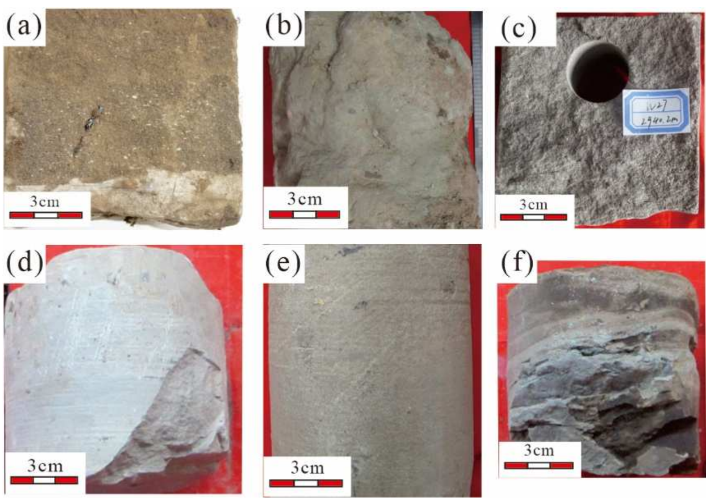
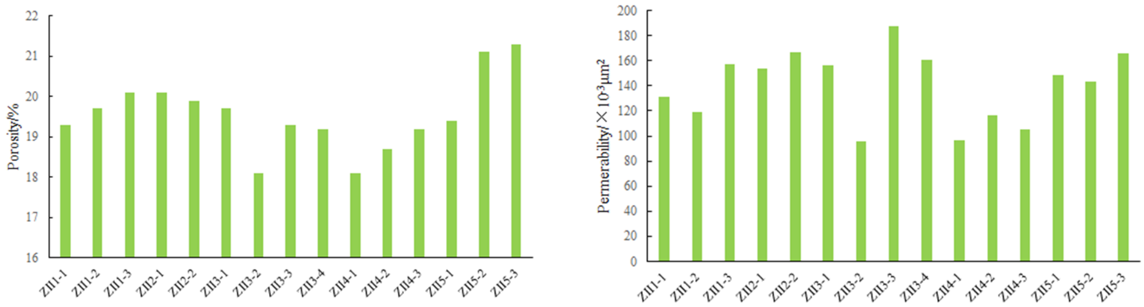


Figure 3. Core photos of Ek1 member in the Wang Guantun Area. (**a**) pebbly sandstone; (**b**) coarse sandstone; (**c**) medium fine sandstone; (**d**) siltstone; (**e**) argillaceous siltstone; (**f**) mudstone.

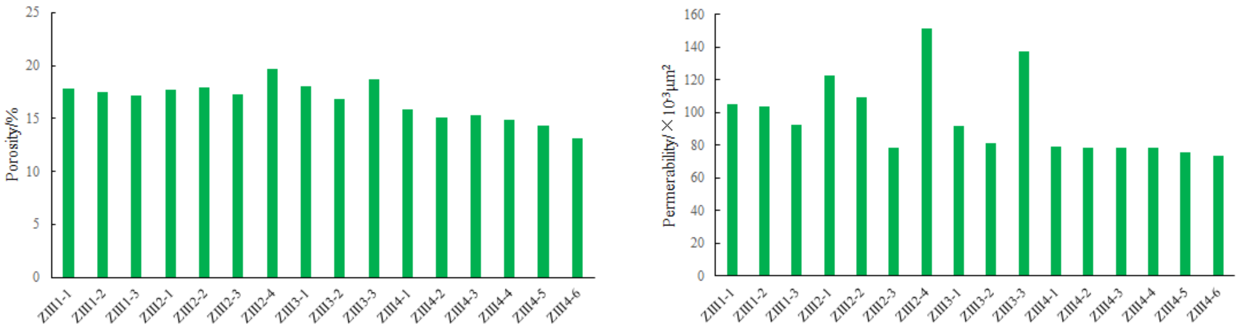
4.2. Porosity and Permeability

The physical property test data and statistical results of the 602 samples from Ek1 member in the Wang Guantun area showed that the physical properties of each oil formation in Ek1 member were different, and the physical properties of ZIII oil formation were relatively poor (Figures 4 and 5). In the ZII oil group, the physical properties of the ZII_4 sublayer was lower and the ZII_5 sublayer was higher. The average porosity was 19.54% and the average permeability was about 140 × 10^{-3} μm^2. The physical properties of each sublayer in the ZIII oil group were quite different. The physical properties of the $ZIII_1$–$ZIII_3$ sublayer were better than those of the $ZIII_4$ sublayer. The $ZIII_1$–$ZIII_3$ sublayer had an average porosity of 18.86% and an average permeability of 107.28 × 10^{-3} μm^2, while the $ZIII_4$ sublayer had an average porosity of 14.67%, and the average permeability was 77.27 × 10^{-3} μm^2.



(**a**) (**b**)

Figure 4. Reservoir properties of sub-sublayers of ZII in the Wang Guantun Area. (**a**) porosity; (**b**) permeability.



(**a**) (**b**)

Figure 5. Reservoir properties of sub-sublayers of ZIII in the Wang Guantun Area. (**a**) porosity; (**b**) permeability.

4.3. Pore Types

According to pore genesis, the pore types of the Ek1 member in the Wang Guantun area mainly included residual intergranular pores and secondary pores. The secondary pores were mainly dissolution pores microcracks (Figure 6).

The number of residual intergranular pores was more in Ek1 formation in the Wang Guantun area, and its pore connectivity was good. Their shapes were often triangular, rectangular, and irregular polygons. The secondary pores were mostly dissolution pores. In the process of hydrocarbon expulsion from source rocks, a large amount of organic acids entered the Ek1 member. Feldspar and rock cuttings were dissolved by organic acids to form dissolution pores. A small number of particles were completely dissolved by acid fluid to form the casting pores. The dissolution pores were irregular in shape, random in distribution and poor in connectivity. The radii of the dissolution pores were generally 5~1000 μm. There were also some pores in clay minerals. These pores were very small and called intercrystalline pores. In addition, there were still a small number of micro-fractures in the Ek1 reservoir, which were caused by late compaction or dissolution. Although the number was small, they made a great contribution to reservoir permeability [18,19].

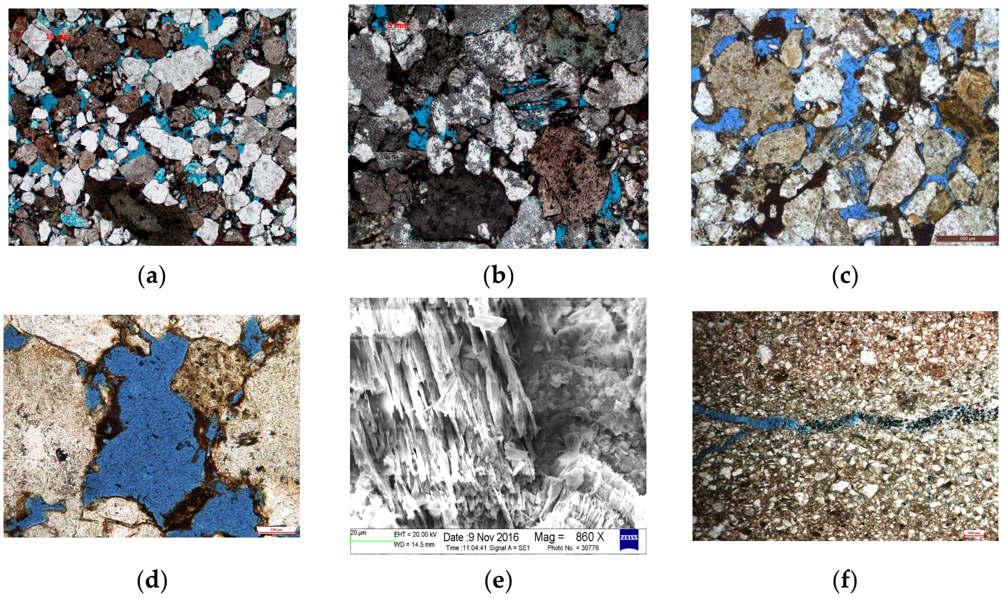


Figure 6. Pore types of reservoirs of Ek1 Formation in the Wang Guantun area. (**a**) Intergranular pore; (**b**) Intergranular dissolution pore; (**c**) Intergranular dissolution pore; (**d**) Mold pore; (**e**) Solution pores in feldspar; (**f**) Microcracks.

4.4. Pore Structure Characteristics

Capillary pressure curves of typical samples were obtained using high-pressure mercury injection and constant rate mercury injection tests, as shown in Figure 7. The capillary pressure curves of different samples had different lengths of "platform sections". When the displacement pressure was generally less than 0.09 MPa, the mercury saturation curve had a relatively stable "platform section". Longer length of the "platform section" indicated that the mercury input continued to increase under the condition of constant pressure, and the pore sorting of the sample was excellent [20]. The pore structure parameters of the sample are shown in Table 2. The average pore radius was 2.213~5.841 μm, and the maximum mercury saturation was 68.4~93.5%. The displacement pressure was negatively correlated with the average pore radius and the maximum mercury saturation (Figure 8a,b), which indicated that the larger the displacement pressure, the smaller the average pore radius and the maximum mercury saturation. Figure 8c,d show that the average pore radius had a positive correlation with porosity and permeability, and the correlation coefficients were 0.758 and 0.629 respectively, indicating that the average pore radius had an obvious control effect on the physical properties of the reservoir. The larger the average pore radius, the better the physical properties of the reservoir.

Table 2. Pore structure parameters of typical samples of Ek1 Formation in the Wang Guantun area.

Well	Depth (m)	Porosity (%)	Permability ($\times 10^{-3}$ μm^2)	Displacement Pressure (MPa)	Average Pore Radius (μm)	Maximum Mercury Saturation (%)	Mercury Removal Efficiency (%)
G78x	2673.4	22.10	236.08	0.063	5.841	93.5	12.9
	2724.5	23.40	355.89	0.054	5.129	90.8	16.3
	2680.7	13.05	229.71	0.091	4.345	85.4	11.6
	2759.1	17.20	118.41	0.090	3.351	81.6	17.5
	2754.1	9.30	62.70	0.091	3.103	74.6	14.8
	2775.8	7.43	85.76	0.130	2.213	68.4	12.5

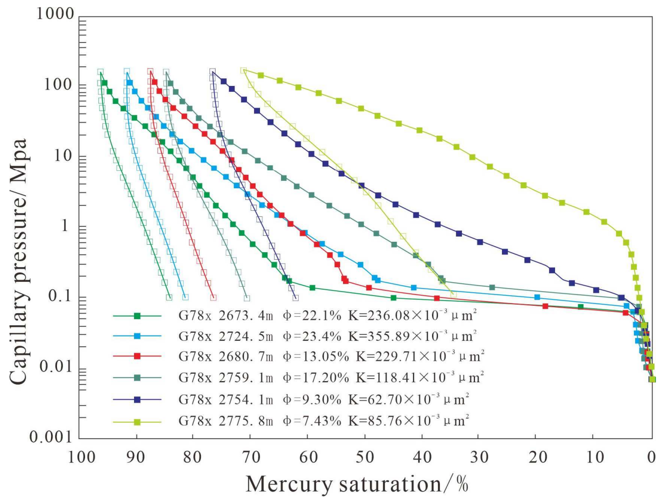


Figure 7. Mercury injection curves from pressure-controlled mercury injection of typical samples of Ek1 Formation in the Wang Guantun area.

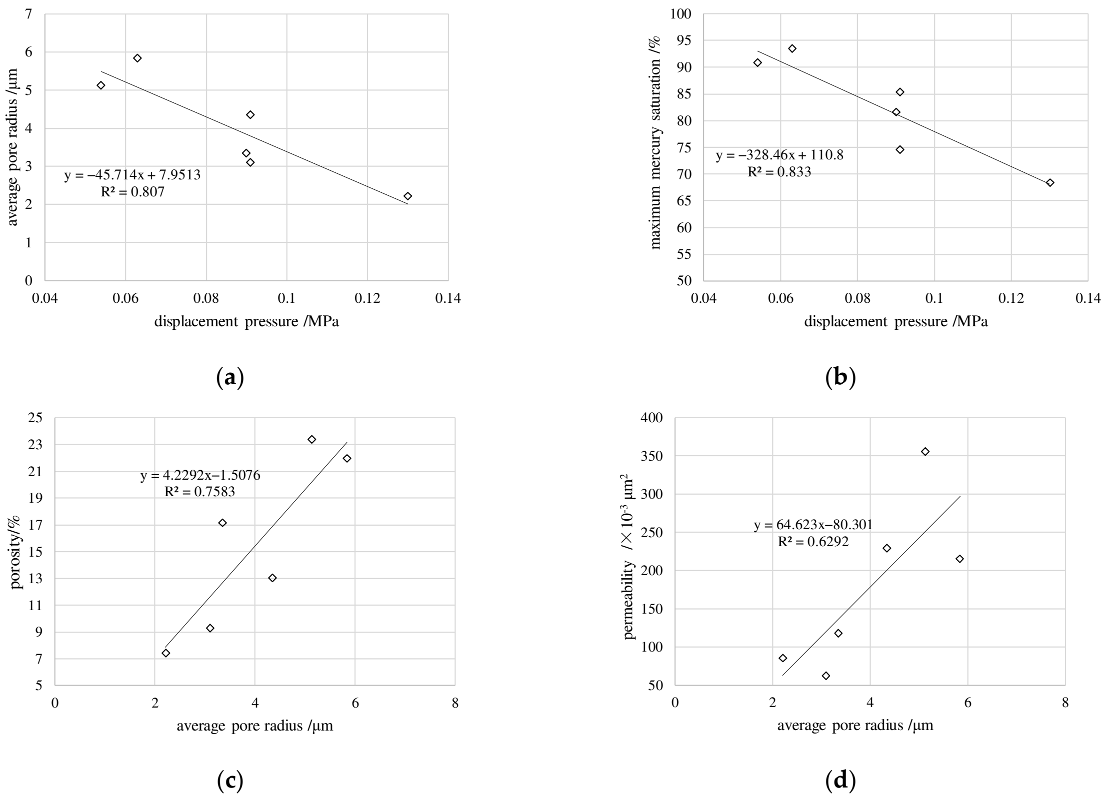


Figure 8. Relationship between parameters of pore structure and porosity, permeability of typical samples of Ek1 member in the Wang Guantun Area. (**a**) displacement pressure and average pore radius, (**b**) displacement pressure and maximum mercury saturation, (**c**) average pore radius and porosity, (**d**) average pore radius and permeability.

5. Discussion

5.1. Control of Sedimentary Conditions on Reservoir Quality

5.1.1. Reservoir Quality Difference of Different Clastic Components

To explain the reservoir difference caused by the difference in rock fragments, the content and physical properties of rock fragment from four wells were counted (Table 3). The results showed that the porosity of well Guan 51-7 and well Guan 50-5, affected by the provenance of Cangxian uplift, were slightly higher than that of well Guan 78-28-2 and well

Wang 23. This was because the content of volcanic rock fragment in the sediments from Xuhei uplift is relatively high and the anti-compaction ability weak. Compaction reduces more intergranular pores. However, on the whole, the physical property difference caused by the difference of rock fragment was not very large, that is, the difference of rock fragment was not the main factor of physical property differences. The statistics showed that porosity increased obviously with increase of the volume fraction of quartz and feldspar, and decreased with increase of the volume fraction of rock fragment (Figure 9). This was because more volume fraction of hard rock fragment can increase the anti-compaction ability of rock. Soft rock fragment often reduces physical properties in the form of the pseudo miscellaneous base, and the hardness of quartz and feldspar is relatively large. Therefore, under the same conditions, the larger the volume fraction of quartz and feldspar, the stronger the pore retention ability.

Table 3. Statistics of rock fragment types and porosity of samples from four wells of Ek1 member in the Wang Guantun Area.

Wells	Rock Fragment/%			Igneous Rock Fragment/%			Metamorphic Rock Fragment/%			Sedimentary Rock Fragment/%			Porosity/%		
	Min	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
G78x	17.7	58.0	30.75	18.6	26.7	22.5	2.1	6.8	4.4	0.6	4.3	3.8	9.1	25.8	18.7
W23	16.0	54.0	33.1	6.2	27.8	23.1	1.9	7.9	5.4	1.3	8.8	4.7	10.5	25.7	19.4
G51-7	11.2	34.3	24.3	2.2	12.5	8.8	1.5	9.6	5.3	2.5	19.5	10.2	4.9	28.7	22.5
G50-5	15.0	53.5	22.2	1.7	10.5	6.8	0.9	8.6	5.4	3.2	16.4	9.8	12.4	31.6	21.2

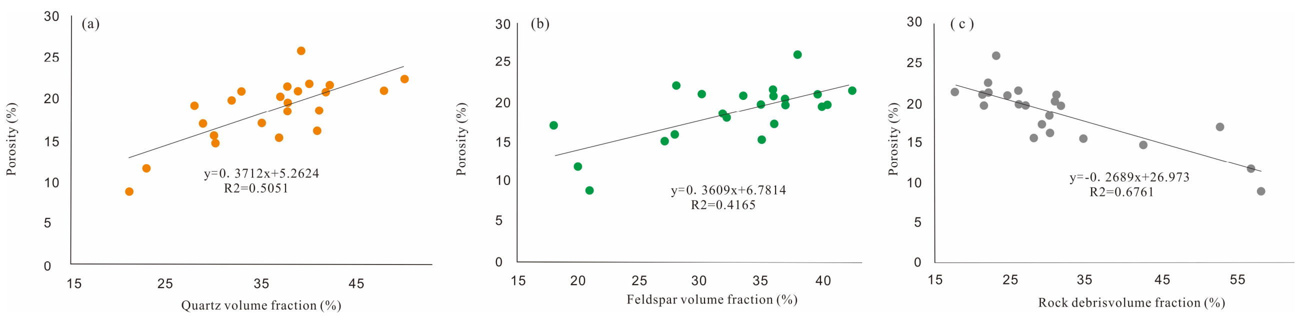


Figure 9. Correlation between clastic composition and porosity of Ek1 Formation in the Wang Guantun area. (**a**) porosity and quartz volume fraction; (**b**) porosity and feldspar volume fraction; (**c**) porosity and rock debris volume fraction.

5.1.2. Control of Sedimentary Fabric on Reservoir Quality

The relationship between the physical properties of Ek1 member in the Wang Guantun area and the particle size of clasts showed that the larger the particle size of clasts, the better the physical properties of reservoirs (Figure 10). With the increase of clastic particle size, reservoir porosity and permeability also increased, because the particle size of clastic particles affected the arrangement and sorting of particles, as well as the later compaction. The larger the particle size, the stronger the anti-compaction ability.

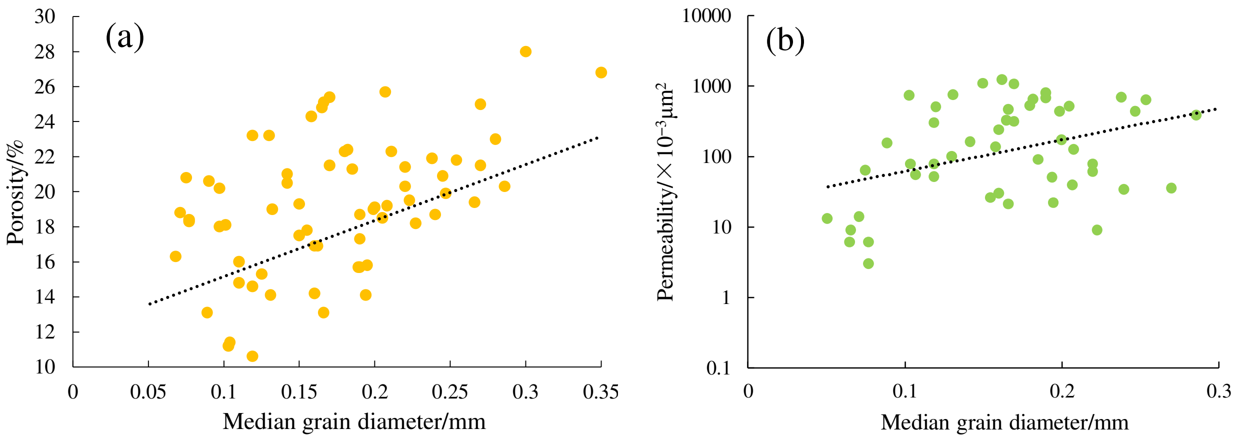


Figure 10. Relationship between particle size and physical properties of ZII_3 in the Wang Guantun area. (**a**) porosity and median grain diameter; (**b**) permeability and median grain diameter.

Reservoir sorting affects reservoir physical properties. The better the sorting, the more uniform the particle size distribution, and the better the reservoir physical properties. On the contrary, when the reservoir sorting is poor, fine-grained sediments are mixed between large particles, occupying the pore space and blocking the throat, which reduces the reservoir physical properties, that is, there is a positive correlation between reservoir physical properties and sorting.

The sorting coefficient (So) was equal to the ratio of P75 and P25. P75 and P25 referring to the particle diameters corresponding to 75% and 25% on the particle size accumulation curve, respectively. Figure 11 shows the sorting coefficient was mainly distributed between 1.18 and 2.2, with an average value of 1.64. The smaller the sorting coefficient, the better the sorting. With increase of the sorting coefficient, the reservoir porosity decreased significantly, that is, the worse the sorting of the reservoir, the smaller the porosity. The correlation between porosity and permeability was strong, and the correlation coefficient was generally greater than 0.85. Therefore, with increase in sorting coefficient, reservoir permeability decreased significantly.

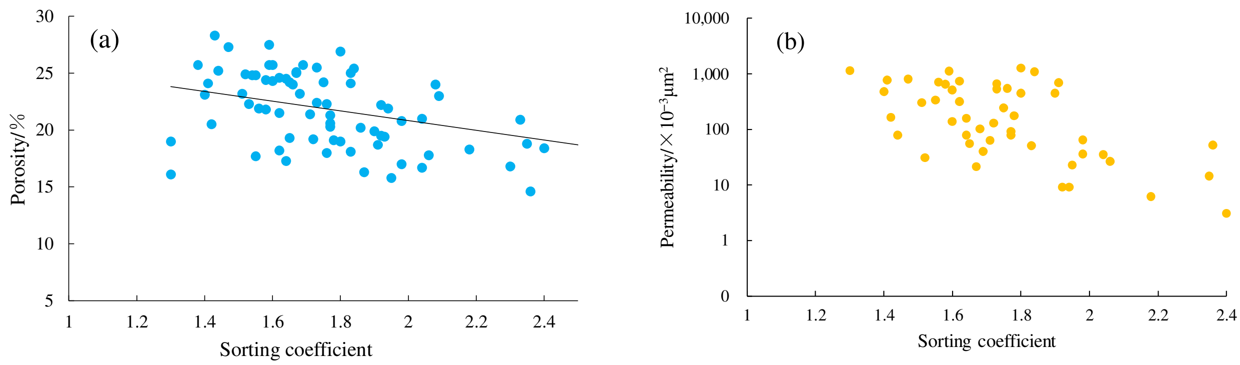


Figure 11. Relationship between sorting and physical properties of ZII_3 in the Wang Guantun area. (**a**) porosity and sorting coefficient; (**b**) permeability and sorting coefficient.

The content of various sedimentary components in the reservoir plays an important role in controlling the original physical properties of the reservoir. Among them, the content of interstitial materials (such as argillaceous matrix and carbonate minerals) have a great impact on the physical properties of alluvial fan sand body reservoir in the study area.

According to the statistics on the relationship between the physical properties and mud content of in Ek1 section in the Wang Guantun area, the results showed that the mud content had an obvious control effect on the reservoir quality in this area. The more the mud content, the worse the reservoir physical properties. As shown in Figure 12, with increase in mud content, the reservoir porosity and permeability decreased. This was because the mud interstitial material occupies the pore space, blocks the throat and reduces the reservoir storage and seepage capacity.

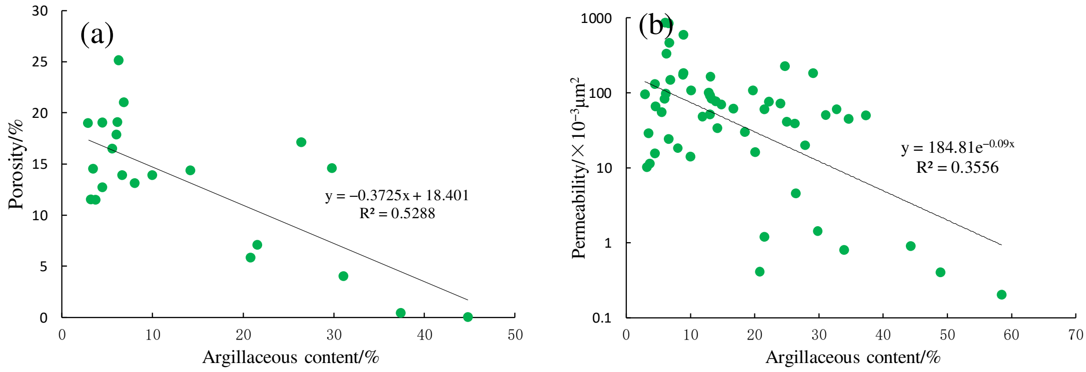


Figure 12. Relationship between shale content and physical properties of ZII_3 in the Wang Guantun area (**a**) argillaceous content and porosity (**b**) argillaceous content and permeability.

5.1.3. Control of Synsedimentary Faults on Reservoir Quality

Different types of faults exist in complex fault block reservoirs, including synsedimentary faults and post sedimentary faults, both of which have obvious control on reservoir quality. The post sedimentary fault can be associated with many secondary faults and fractures, increasing the permeability of the reservoir. Synsedimentary faults can control the grain size of reservoirs and the development of dissolution pores. The stronger the intensity of synsedimentary fault activity, the more developed the dissolution pores [14].

5.2. Control of Diagenesis on Reservoir Quality

5.2.1. Control of Compaction on Reservoir Quality

The altitude depth of Ek1 reservoir was 1500~3800 m. Multi-stage compaction greatly reduced the intergranular volume. The lithology of the hanging wall of Kongdong fault is mainly feldspathic lithic sandstone, and the lithology of the ascending wall of Kongdong fault is mainly lithic feldspathic sandstone with a small amount of feldspathic sandstone. The research showed that the content and type of rock debris, the content of rigid particles, and the particle size of debris particles all affected the later compaction. The less the content of plastic rock debris, the larger the particle size of debris, the higher the content of rigid particles, the stronger the anti-compaction ability and the larger the volume of retained intergranular pores.

The microscopic appearance of the Ek1 reservoir in the Wang Guantun area showed that the particle contact relationship was line contact (Figure 13a), with line concave–convex contact characteristics, and suture contact could also be seen under strong compaction (Figure 13b). When the overlying pressure exceeded the maximum bearing pressure of rock particles, feldspar and quartz particles ruptured along the joint surface (Figure 13c).

The compaction of Ek1 member in the Wang Guantun area was dominated by mechanical compaction. Under the action of mechanical compaction, the density of rock increases, and the primary pores decrease greatly. The volume of intergranular pores in the rock can indicate the degree of compaction of clastic rocks. The pore volume gradually decreases during the continuous compaction process. Assuming that the original porosity of Ek1 reservoir in the Wang Guantun area was at most 40%, the relative loss of primary porosity caused by the compaction of the descending wall of the Kongdong fault was between 15% and 90%, and the relative loss of primary porosity caused by compaction of the rising wall of the Kongdong fault was between 10% and 75%. This was due to the rapid deposition of sediments in the descending wall of the Kongdong fault, poor sorting, and greater burial depth. The compaction had a more obvious porosity reduction effect on the reservoir of the descending wall of the Kongdong fault.

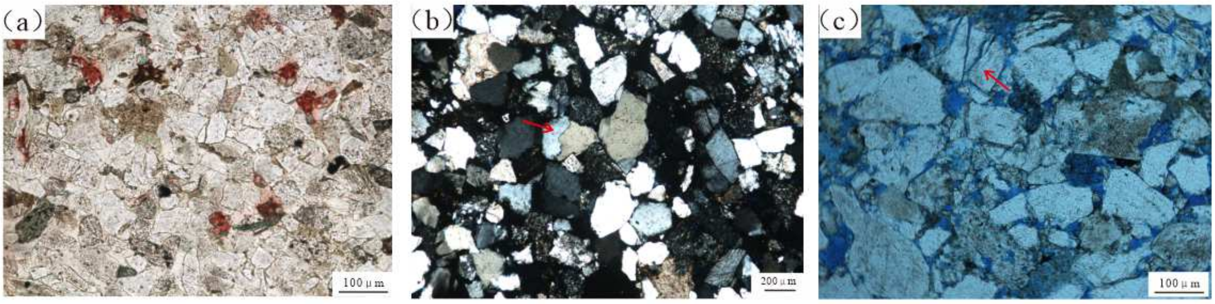


Figure 13. Compaction characteristics of Ek1 Formation in the Wang Guantun area (**a**) Well G50-5 1917.5 m (**b**) Well G106 3053.75 m, arrow refers to concave–convex contact (**c**) Well G11-13 2467.34 m, arrow refers to fracture.

Compaction also has different porosity reduction effects on different rock types. According to statistics, the porosity reduction degree of feldspar sandstone is significantly lower than that of feldspar cuttings sandstone. Figure 14 shows that when the compaction rate was greater than 60%, both porosity and permeability were inversely proportional to the compaction rate. When the compaction rate was less than 60%, the porosity and permeability of the reservoir changed a little with the change in the compaction rate. In this case, the porosity reduction effect of compaction on the reservoir was not obvious, and the existence of cement in the pores could weaken the compaction effect, while, at the same time, also leading to reduction of pore space.

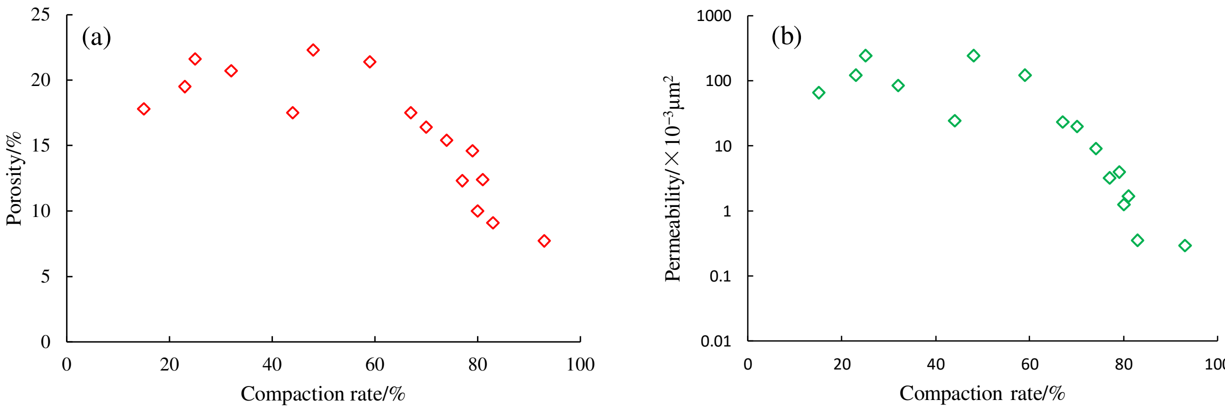


Figure 14. The relationship between porosity, permeability and compaction of Ek1 Formation in the Wang Guantun area. (**a**) porosity and compaction; (**b**) permeability and compaction.

5.2.2. Control of Cementation on Reservoir Performance

Through thin section observation and SEM analysis, the cementation in Ek1 reservoir in the Wang Guantun area mainly included carbonate cementation, clay mineral cementation and siliceous cementation.

Carbonate cementation was common in the Ek1 reservoir of the Wang Guantun area, with an average carbonate content of 7.06%, mainly ferrocalcite and locally ferrodolomite cementation. Ferrocalcite mainly filled residual intergranular pores and metasomatic clastic particles or oolites (Figure 15a,b). In the samples with developed calcite cementation, the dissolution was weaker. In addition, the degree of carbonate cementation varied within a composite sand body unit, ranging from strong cementation to weak cementation. From the distribution of carbonate cement, near the sand-mudstone interface, there was more carbonate cement, which meant that carbonate content was preferentially deposited on the top and bottom of the sand body, such as at Guan 78-28-2 Well.

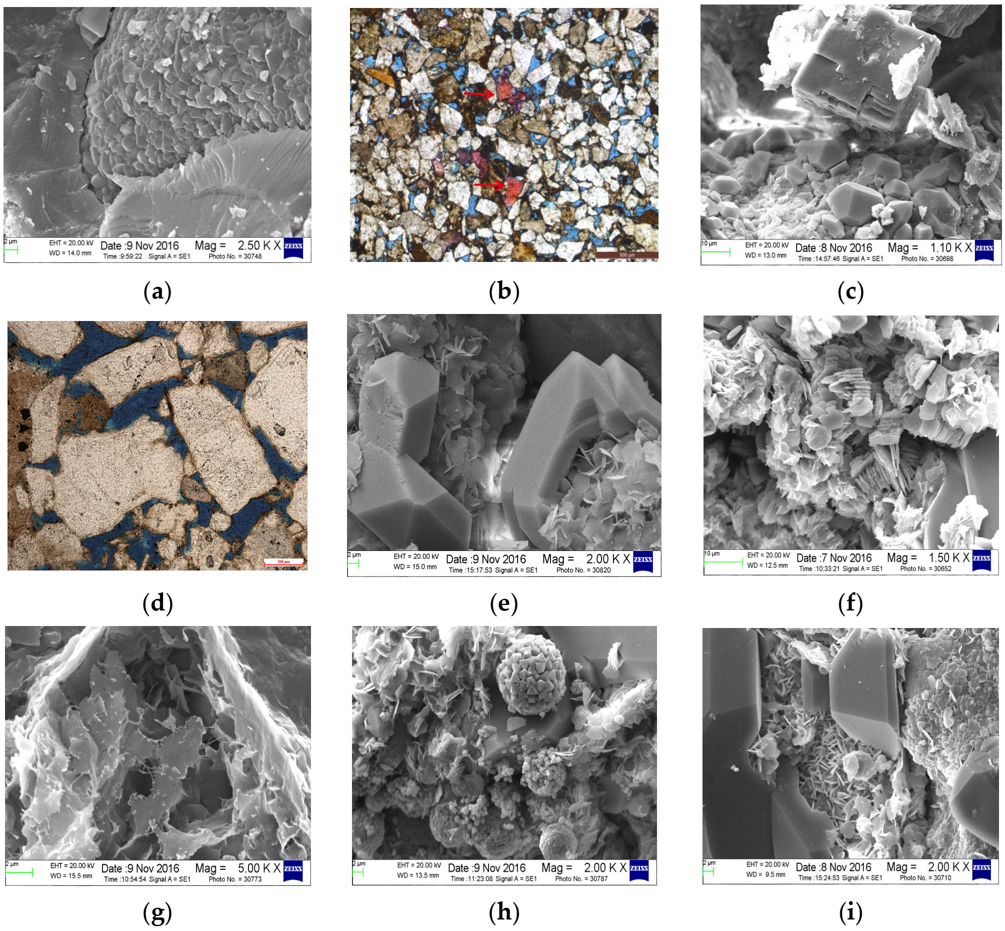


Figure 15. Cementing features. (**a**) Calcite; (**b**) Ferroan calcite; (**c**) Dolomite; (**d**) Secondary quartz; (**e**) Authigenic quartz; (**f**) Kaolinite; (**g**) Filiform Illite; (**h**) Pyrite; (**i**) Coniferous chlorite and Filiform Illite.

Quartz secondary enlargement refers to single crystal quartz particles around which sediments proliferate during diagenesis. The phenomenon of quartz secondary enlargement in Ek1 member in the Wang Guantun area is common. Through the observation of rock thin section and scanning electron microscope, it was found that the quartz secondary enlargement edges were mostly iso-thick annular around the quartz particles, and the width of the enlarged edge was generally about 20 μm. The existence of dust lines made the boundary between clastic particles and enlarged edges very clear (Figure 15d). When clay minerals were wrapped on the surface of quartz particles, the quartz secondary enlargement was inhibited (Figure 15i). On the one hand, quartz secondary enlargement filled the pores and changed the original arrangement of particles. On the other hand, it inhibited the generation of secondary pores and made the reservoir physical properties worse.

The content of authigenic clay minerals ranged from 3% to 31%, with an average content of 8.85%. There were many types of clay mineral cementation, including kaolinite, chlorite, illite, chlorite-montmorillonite mixed layer, and illite-montmorillonite mixed layer cementation, among which the content of illite-montmorillonite mixed layer was the highest, followed by chlorite, and the content of chlorite-montmorillonite mixed layer was the lowest.

Under the scanning electron microscope, it was found that there were many forms of chlorite, mainly needle-leaf, rose-like, and fluffy ball-like, which mainly occurred in granular film type and pore filling type (Figure 15). On the one hand, the existence of chlorite film increased the anti-compaction ability of rock. On the other hand, because of the separation of rock particles and formation water by chlorite film, quartz secondary enlargement was further inhibited, which could be intuitively found under the scanning electron microscope.

In Ek1 reservoir, illite and illite-montmorillonite mixed layers were abundant and widely distributed. Most of them were filled between pores in the form of silk flakes and bridges, occupying the pore space of the reservoir and reducing the connectivity between pores. The content of kaolinite was medium, and its content was closely related to the dissolution of feldspar. The dissolution of feldspar could be transformed into kaolinite so that kaolinite occurred in situ where the feldspar dissolved. The dissolution of Zao IV and V oil groups in Ek1 member was strong, and the content of kaolinite was high, indicating that the diagenetic system was relatively closed.

5.2.3. Control of Dissolution on Reservoir Quality

The dissolution pores of Ek1 in the Wang Guantun area were developed, mainly including intragranular dissolved pores and intergranular dissolved pores. The lithology of this area is mainly lithic feldspathic sandstone and feldspathic lithic sandstone. A large number of feldspar and volcanic rock debris and other soluble substances provide material contact for dissolution. The intragranular dissolved pores were formed by partial dissolution of feldspar particles, the dissolved pores of cuttings and the intergranular dissolved pores. The dissolution was accompanied by a small amount of autogenous kaolinite, illite, and quartz (Figure 6).

In the Wang Guantun Area, the development degree of dissolution pores in different well areas varied greatly. Figure 16 shows the plane porosity of dissolution pores (PPDP) in different well areas on the plane, and the average plane porosity of dissolution pores in Guan 3 and Guan 195 well areas was larger, distributed between 5.5% and 10.5%. The average plane porosity of dissolution pores in Guan 104, Guan 11-5, Guan 143, and Guan 109-1 well areas was medium, mainly distributed between 3.2% and 9.6%. The average plane porosity of dissolution pores in Guan 155 and Guan 80 well areas was the smallest, generally between 1.5% and 3.2%.

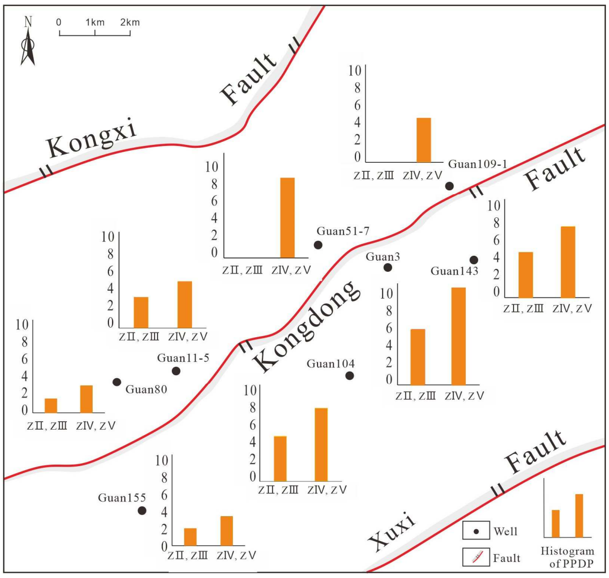


Figure 16. Distribution of PPDP of Ek1 member in the Wang Guantun Area.

Dissolution plays a very important role in the improvement of reservoir quality. After sediment deposition, compaction and cementation generally lead to rapid decrease of reservoir physical properties and the deterioration of reservoir quality. Only when filled with acidic fluid, can the soluble material in the rock dissolve, and the reservoir be effectively improved. The relationship between porosity and physical properties of Kong 1 reservoir in the Wang Guantun area was statistically analyzed. The results showed that the development of dissolved pores significantly improved the porosity of the reservoir. In Figure 17a, it can be seen that when PPDP was 1.5~3.5%, the porosity had not significantly increased, that is, the development of dissolution pores had no obvious contribution to porosity when there were few dissolution pores. When PPDP was 3.5~9.2%, porosity increased gradually with the increase of PPDP, and the dissolution improved the physical properties of the reservoir. When PPDP was greater than 9.2%, the porosity increased significantly with the increase of PPDP. That is, the porosity of the reservoir was greatly improved by PPDP in this range. Figure 17b shows that there was no obvious relationship between PPDP and permeability, which showed that the dissolution did not significantly improve the permeability of the reservoir of Ek1 member in the Wang Guantun Area. This might be because the dissolution was mainly the intragranular dissolved pores formed by the partial dissolution of feldspar particles, the dissolved pores of rock cutting, and the intergranular enlarged dissolved pores. The pore heterogeneity was strong and the connectivity was poor, which increased the reservoir space and did not increase the reservoir seepage.

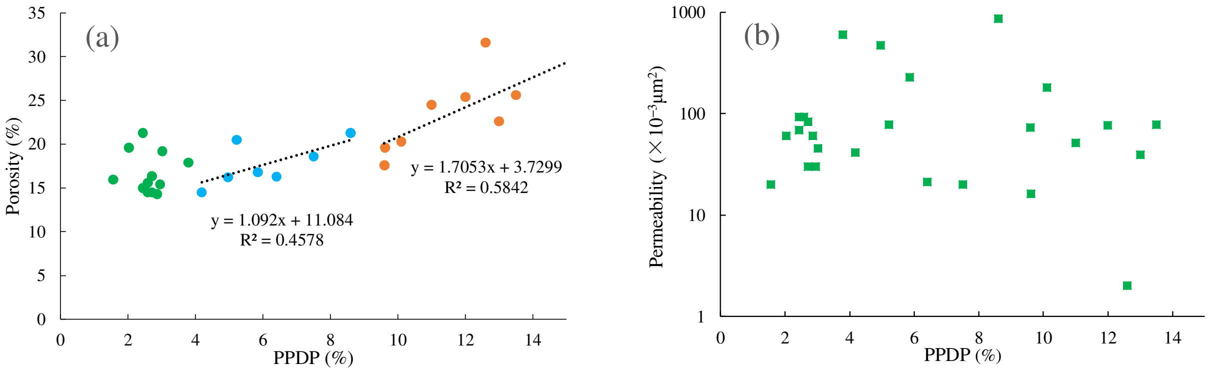


Figure 17. Relationship between plane porosity of dissolution pores. (**a**) porosity; (**b**) permeability of Ek1 Formation in the Wang Guantun area.

6. Conclusions

Reservoir quality varies greatly in complex fault block oil and gas fields, and its control factors mainly include sedimentation, diagenesis, and tectonism. However, which factor plays a leading role requires a detailed analysis based on core, seismic, and logging data. Through the research of this paper, the following conclusions were obtained:

(1) The content of quartz, feldspar, and rock debris has a significant control on reservoir quality. With increase in quartz and feldspar content, reservoir performance gradually increases, and the content of rock debris has a significant negative correlation with porosity.

(2) The compaction of Ek1 reservoir in the Wang Guantun area is mainly mechanical compaction. When the compaction rate is greater than 60%, porosity and permeability are inversely proportional to the compaction rate. When the compaction rate is less than 60%, porosity and permeability of the reservoir change little, indicating that, in this case, the effect of compaction on reservoir pore reduction is not obvious.

(3) The dissolution pores of Ek1 reservoir in the Wang Guantun area are relatively developed. Dissolution plays a very important role in improving the quality of the reservoir. The porosity of the reservoir is greatly improved by the surface porosity of dissolved pores in this range. There is no obvious relationship between the porosity and permeability of dissolution pores, indicating that dissolution did not significantly improve the permeability of the reservoir in the Ek1 member of the Wang Guantun area.

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