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Microscopic and X-ray fluorescence researches on sandstone from Shahejie Formation, China

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Abstract: -The sandstone core samples from Shahejie Formation, Wenliu Oilfield were analyzed with the help of microscopic, petrophysical methods and X-ray fluorescence. By relating their results, it is able to find out the factors that affect the permeability. The samples are determined as fine-particle, porous, homogeneous but low permeable sandstones. The reason for this characteristic lies in the high content of carbonate. Although the dissolution of feldspar and carbonate enlarge the porosity, the honeycomb structure makes it low permeable. Besides, the carbonate recrystallized as cement and blocked capillary. The authors conclude that acidification fracturing can be a method to improve the permeability.

Keywords: *-microscopy, petrophysics,Shahejie Formation, Wenliu Oil Field,X-ray fluorescence*

I. INTRODUCTION

The increasing energy consumption in China is in the present a major challenge. After long exploration and production oilfields such as Wenliu Oilfield stepped already in the phase of decreasing. The water cut is already 99%. It can usually be obtained only 30% of all proven reserves. Much of the oil is located in small pore space into nano range. It is difficult or not economical to produce such oil with today's technology. Therefore, it is increasingly important to analyze the reservoir rocks, to find solutions so that more of the remaining oil can be produced as effectively as possible.

In this article petrographic studies were done and related to the previous result of petrophysical measurements on the sandstone samples from Shahejie Formation, Wenliu Oilfield. The work presents the factors affecting the permeability of the sandstone reservoir and gives possible solutions to improve the permeability.

II. WENLIU OILFIELD

Dongpu Depression lies in the southwest of Bohai Bay Basin and has an area of 5300 km^2. In this region, oil and gas has been produced for over 50 years. Wenliu Oilfield is located in the middle of the central uplift in south Dongpu Depression, adjacent to Pucheng Oilfield in the north. In the south, Qiaokou oilfield is situated on the other side of the Yellow River. The Wenliu structure formed as a diapir in Paleogene due to the upwelling of the underlying salt (see Fig. 1). In the central part of the structure, the reservoir layers are thin, while thickness of the layers on the wing side is much larger. During the formation of diapir formed a plurality of the NE-SW striking faults, so the structural oil and gas reservoirs are characterized by abnormal high pressure and multi-fault blocks (i.e., [1]).

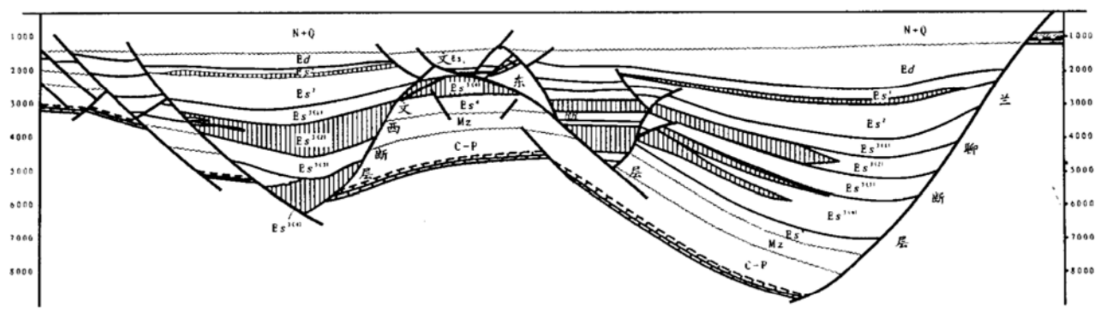

Figure 1Structural profile of Wenliu hydrocarbon reservoir (source: i.e., [2]).

Shahejie (Sha) Formation, the most significant reservoir in this area, covers almost the whole Bohai Bay Basin, and has a large thickness of over 2000 m. The formation is composed of several sedimentary cycles, which mainly consist of claystone and sandstone, indicating the repeated water progression and regression caused by terrain lifting. Shahejie Group can be divided into 4 Members, from top to bottom are named as Sha 1

(E3s1) to Sha 4 (E2s4) Member. The main reservoir is the lower part of Sha 2 Member and the middle and upper parts of Sha 3 Member.

III. PETROPHYSICAL ANALYSIS

The core samples used for research were obtained from 6 wells of the Paleogene Shahejie Formation, Wenliu Oilfield, Dongpu Depression. The original depth ranges from 3332 m to 3738 m. The samples are all 30 mm long cylinder with a diameter of 25 mm. Before the microscopic research, a couple of petrophysical measurements were done, and the samples were renamed for case of comparison (see Table 1).

Table 1 Result of petrophysical measurement (source: i.e., [3]).

No.	New No.	Grain Density [g/cm^3]	Porosity	Permeability [mD]	Specific Surface [1/μm]
Wen 13-20-1	SS-1	2.700	11.4%	0.129	48.321
Wen 13-20-2	SS-2	2.666	17.2%	18.279	17.943
Wen 13-20-3	SS-3	2.671	17.0%	25.056	12.131
Wen 13-20-4	SS-4	2.665	15.3%	60.502	3.387
Wen 13-20-5	SS-5	2.647	15.4%	45.680	7.360
Wen 13-26-8-1	SS-6	2.670	13.8%	0.081	97.350
Wen 13-26-8-2	SS-7	2.670	13.9%	0.130	113.602
Wen 13-26-8-3	SS-8	2.679	14.6%	0.227	114.772
Wen 13-26-8-4	SS-9	2.672	13.7%	0.364	142.275
Wen 13-26-8-5	SS-10	2.671	13.8%	0.432	129.709
Wen 13-26-11-1	SS-11	2.659	12.0%	0.624	65.408
Wen 13-26-11-2	SS-12	2.656	12.7%	1.297	64.355
Wen 13-26-11-3	SS-13	2.652	14.9%	7.050	19.549
Wen 13-26-11-4	SS-14	2.654	14.0%	5.961	20.960
Wen 13-26-11-5	SS-15	2.643	13.4%	1.878	44.682
Wen 13-50-1-1	SS-16	2.659	14.3%	9.006	9.351
Wen 13-50-1-2	SS-17	2.659	12.6%	10.919	14.462
Wen 72-433-5-1	SS-18	2.652	15.8%	23.651	4.567
Wen 72-433-5-3	SS-19	2.679	7.7%	0.043	56.555
Wen 72-453-4-1	SS-20	2.662	13.3%	14.286	6.905
Wen 72-453-4-2	SS-21	2.661	10.0%	3.591	11.269
Wen 72-453-10-1	SS-22	2.667	10.2%	0.046	35.608
Wen 72-453-10-2	SS-23	2.659	13.0%	2.217	11.803
Wen 16-36	SS-24	2.710	6.2%	0.017	75.235

According to the results, the grain density of the samples varies from 2.64to 2.67 g/cm^3, which is close to the density of quartz. That means quartz plays an important role as a dominant mineral in the sandstone. However, the SS-1 and SS-24 have a larger density indicating a different composition of component. In porosity, most samples belong to a medium level as reservoir with a value of 10%-15%. Permeability, one of the most significant parameter for reservoir, was measured with nitrogen and used for classification of the samples (see Table 2). The following analysis also focused on factors affecting the permeability. In the end, specific surface area was calculated with:

$$S_{pore} = \frac{A}{V_{pore}}.$$

In the formula A is the internal surface area, V_{pore} is the volume of pore space, and S_{pore} is specific internal surface area. It reflects the tortuosity and diameter of pore space, and apparently the samples with high S_{pore} value are usually low permeable.

Table2 Classification of samples with permeability.

Class		Sample
H-P	(>60mD)	SS-3, 4, 5, 18
M-P	(2～60mD)	SS-2, 13, 14, 16, 17, 20, 21, 23
L-P	(<2mD)	SS-1, 6, 7, 8, 9, 10, 11, 12, 15, 19, 22, 24

IV. MICROSCOPIC ANALYSIS

By polarized microscopic and electron microscopic observation, mineral composition and micro structures inside were further determined. SS-1, 3, 5, 9, 11, 13, 14, 16, 18, 22 and 24 samples were selected for the study of the polarized microscope. The samples have overall similar mineral composition and are particle supported. Porosity, sorting, psephicity and some other aspects are slightly different (see Table 3). The porosity is estimated at 7%-18%, and about 80% of the pores are secondary ones formed by dissolution of feldspar and carbonate. Due to the great buried depth, the grains were strong compacted, which changed the point contact to line contact and suture contact. In addition, secondary enlargement of quartz and carbonate cementation appears frequently in the samples.

Table3 Result of observation under polarized microscope.

Sample	Components				Porosity	Psephicity	Sorting
	Quartz	Feldsp	Carbonate	Debris			
SS-1	60%	25%	10%	5%	10%	angular	well
SS-3	64%	25%	7%	4%	15%	sub-rounded	moderate
SS-5	55%	30%	10%	5%	18%	rounded	moderate
SS-9	63%	22%	7%	8%	12%	sub-rounded	bad
SS-11	65%	20%	7%	8%	15%	sub-rounded	moderate
SS-13	55%	30%	10%	5%	10%	rounded	moderate
SS-14	60%	25%	5%	10%	15%	angular	bad
SS-16	60%	25%	7%	8%	12%	angular	well
SS-18	65%	20%	5%	10%	15%	rounded	well
SS-22	68%	20%	7%	5%	10%	rounded	very well
SS-24	58%	12%	28%	2%	7%	sub-rounded	moderate

As shown in Figure 2, the grain size of sandstone is fine, with an average diameter of about 100 μm. According to the content of each mineral the samples can be defined as debris-feldspar sandstone and feldspar-quartz sandstone. In accordance with the feature of Fig. 2, it is indicated that quartz enlargement phenomenon in mineral sheet is very common, illustrating that during the deposition, the high regional sedimentation rate caused high pressure and temperature. This led to a high concentration of Si^{4+} in formation fluid, and recrystallization of quartz by flowing through reservoir (i.e., [4]).

Most of the pores in the rock were generated by the dissolution of feldspar and carbonate. Some feldspars are not completely dissolved, and the residual part has high porosity, but the honeycomb structure makes the pores have small diameters, which leads to low permeability. In relation to the result of petrophysical measurement, this also explains why some samples have high porosity but low permeability. The high content of carbonate in the rock indicates that in the early stage of deposition process, the carbonate debris, quartz and feldspar were deposited at the same time, then they experienced sedimentation and diagenesis. The carbonate in rock was partly dissolved, making the calcium carbonate content in formation water increase, so when the temperature and pressure changed, the carbonate crystallized out and cemented grains.

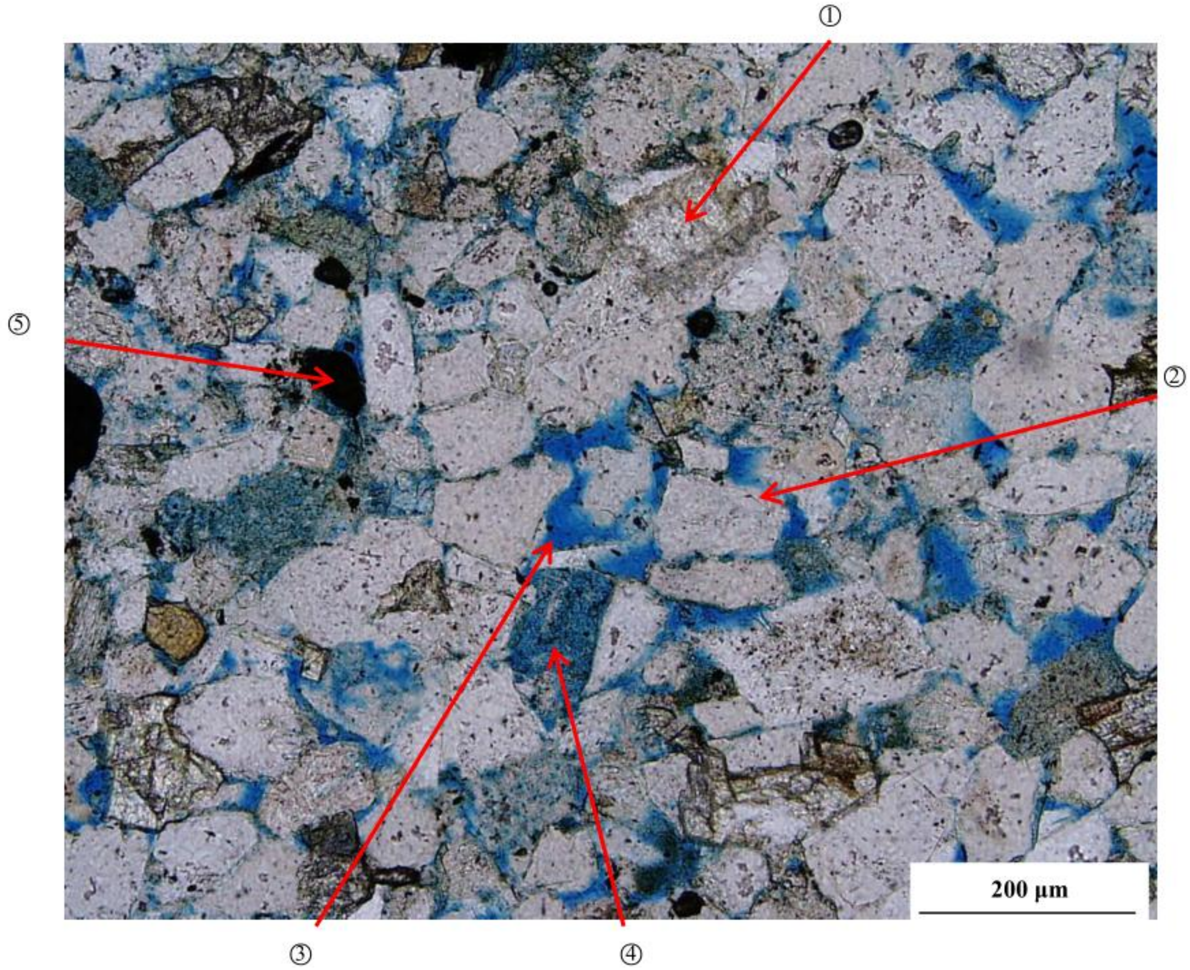

Figure 2 SS-16 under 10x polarized microscope.

① Carbonate cement
② Quartz overgrowth
③ Primary porespace
④ Secondary porespace
⑤ Opak

More detailed observation of the various phenomena was done with electron microscope. Fig. 3a shows the quartz overgrowth, which makes some of the quartz particles form a smooth and complete surface, and also illustrates the high pressure environment caused by land subsidence. 3b is partly dissolved feldspar grains. This phenomenon increase, although the porosity, as capillary radius is too small, is of no positive significance. In addition, these tiny pores may be the reason why some samples have large specific internal surface. As shown in Fig. 3c, a small amount of illite was found in SS-24, but because of the low content it did not form pore-bridging structure, which influences the formation permeability. 3d is for a small amount of calcite cement.

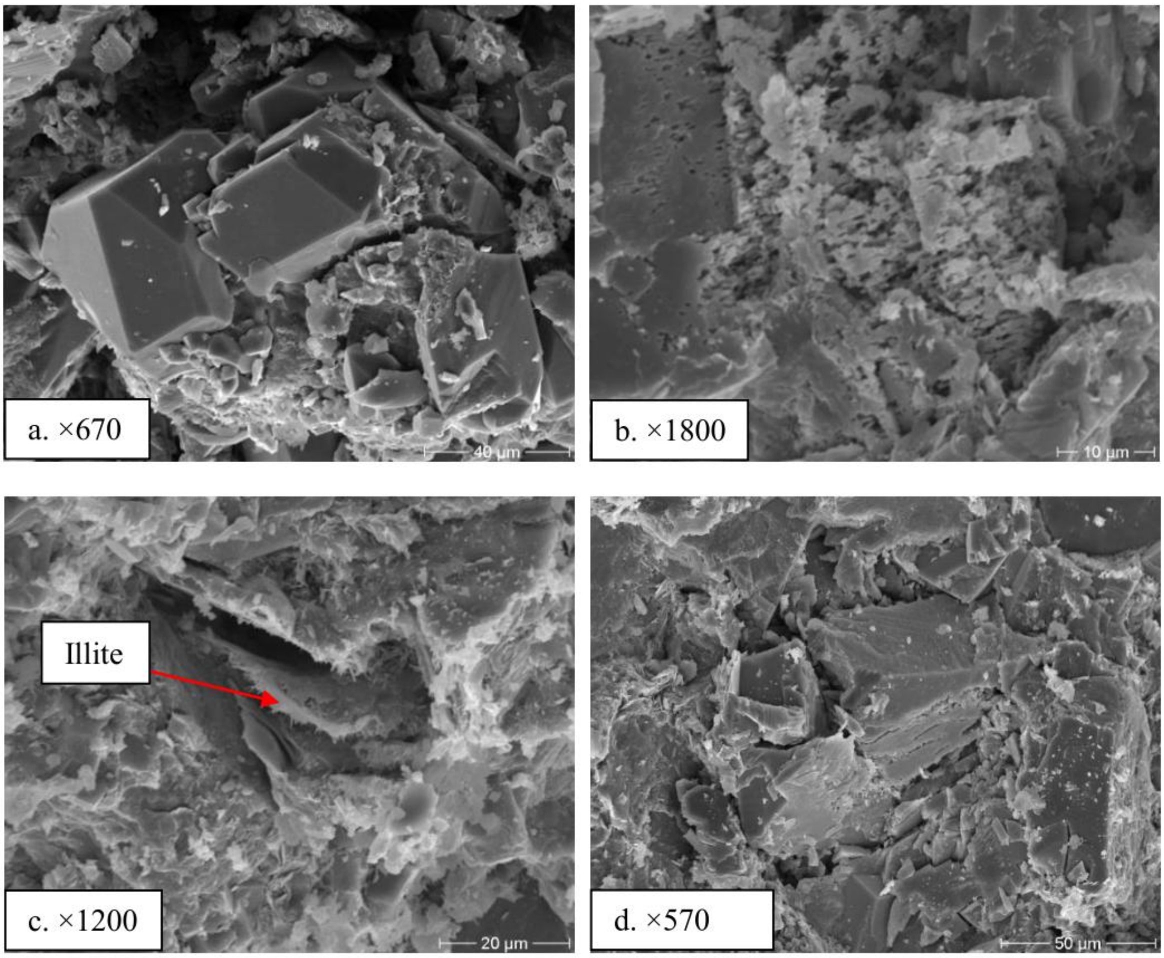

Figure 3 SS-16 under electron microscope.

V. X-RAYFLUORESCENCE ANALYSIS

X-ray fluorescence analysis was done to detect the chemical composition of the rock and the contents of the significant elements. Table 4 is the detection result of X-ray fluorescence analysis. The main elements are presented in the form of oxides. CaO content is converted to $CaCO_3$ to fill up the lack of detection of the CO_3^{2-}, and makes the total amount approach to 100%. As shown in the table, the iron content in the sample is high, while magnesium is low, indicating that the majority of carbonate minerals in the rocks are ferrocalcite, and a small amount of ferrodolomite. The $CaCO_3$ content of each sample was significantly different. It is high in SS-24, while the quartz content is low, and the results are consistent with the results of microscopic analysis. Other samples have similar composition. In SS-5, 14 and 18, quartz content is over 70%, and calcium carbonate content is less than 8%, indicating that the carbonate has a negative effect on the permeability.

Table 4 Result of X-ray Fluorescence Analysis.

sample		SS-24	SS-18	SS-14	SS-9	SS-5	SS-3	SS-1
Sum	(%)	97.65	98.81	98.33	98.02	94.61	96.96	96.24
Result	check	Concentration						
Na_2O	(%)	1.96	3.68	2.72	2.35	3.51	3.39	3.03
MgO	(%)	3.68	1.64	1.46	1.69	0.99	1.99	1.61
Al_2O_3	(%)	6.91	8.83	8.26	9.99	7.74	8.12	9.14
SiO_2	(%)	56.72	73.91	72.96	67.73	70.2	68.56	62.74
P_2O_5	(%)	0.068	0.124	0.069	0.09	0.05	0.059	0.134
Cl	(%)	0	0.01	0	0	0.01	0.01	0.01
K_2O	(%)	1.11	1.12	0.99	1.89	0.46	0.59	0.88
$CaCO_3$	(%)	22.03	6.41	8.87	10.85	8.80	10.01	14.92
TiO_2	(%)	0.265	0.407	0.286	0.386	0.164	0.215	0.482
MnO	(%)	0.256	0.05	0.06	0.055	0.058	0.12	0.077
Fe_2O_3	(%)	4.54	2.37	2.4	2.79	2.02	3.57	2.99

VI. SUMMARY

The sandstone samples from Shahejie Formation, Wenliu Oilfield, Dongpu Depression are fine-particle, porous and homogeneous. The grain size varies from 50 to 200 μm. According to the petrophysical analysis, the sandstone samples are classified into three levels, which are high, medium and low on the basis of their permeability. The porosity of the high permeability samples is also high, so the reservoir physical property is good. The medium and low permeable samples have a large difference, either have a certain permeability, but the porosity is low, or there is a high porosity but no good connectivity.

The main factors leading to low permeability and porosity are found by the analysis of microscope. In some fine-grain samples (such as SS-1), although the particles have good sorting, but the pore space between the particles was due to strong compaction dramatically reduced, the pore radius is so small that it leads to low permeability. In addition, carbonate cements have a great influence on permeability. During the deposition of sandstone, a certain amount of carbonate debris were also deposited. By diagenesis the carbonate in the rock was partly dissolved in the formation water, and later due to the high concentration in formation water and changes of temperature and pressure they separated out and formed the cements. The appearance of the cement also affects the permeability of the rock. The SS-24 sample is a typical example.

In summary, the sandstone of Shahejie formation belongs to porous but low permeable type of reservoir. Considering the characteristics of its high content of carbonate, acid can be helpful. On one hand it will enlarge the pore volume by dissolving carbonate particles, on the other hand the dissolution of carbonate cement will enhance the connectivity of pore space. So the acidification fracturing can be used to improve its permeability, so as to achieve the purpose to sustain production.

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