ENVIRONMENTAL AND EARTH SCIENCES RESEARCH JOURNAL
Vol.2, No.2, 2015, pp.7-12
http://dx.doi.org/10.18280/eesrj.020202

THE RESEARCH ON THE METHOD OF INDENTIFYING LOW RESISTIVITY RESERVOIR IN ZHUSAN DEPRESSION OF THE PEARL RIVER MOUTH BASIN

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ABSTRACT

The exploration and development of low resistivity reservoir have received considerable attention. Highly mineralized formation water, high clay content, the development of micro-fracture, thickness, etc-all of them are the reasons for the formation of low resistivity reservoir. Based on the analysis of the reasons for the the formation of low resistivity reservoir in Oil group ZJ1-4 of Oilfield M and Oil group ZJ1 of Oilfield N of Zhusan Depression, Pearl River Mouth Basin, and the geological features of the two different oilfields, resistance enhancement rate is used to identify low resistivity reservoir and frequency matching method is used to improve the resolution of the resistivity curve. The thesis analyzes individual oil group and intends it to be a guidance and inspiration for other explorations.

Keywords: Low resistivity reservoir, Causes for low resistivity, Resistance enhancement rate, Frequency matching method.

1. INTRODUCTION

Low resistivity reservoir is different from conventional oil reservoir. Research shows that low resistivity reservoirs are widely scattered across the world: the Gulf of Mexico in the US, east offshore areas of Canada, the Middle East, eastern and western oil fields in China. For example, low resistivity reservoirs are found in Bohaiwan basin, Songliao basin, Tarim basin, Ordos basin, and have considerable amount of oil reserve[1]. With the development of well logging technology, the development and exploration of low resistivity reservoir have caught wide attention. The resistance value of low resistivity reservoir is extremely close to that of adjacent aqueous layer and surrounding rock, which poses a difficulty for distinguishing oil layer and aqueous layer. Thus, the evaluation of low resistivity reservoir has become a common and difficult topic in the field of well logging interpretation.

This thesis discusses the electrical property of low resistivity reservoirs in Oil group ZJ1-4 of Oilfield M and Oil group ZJ1 of Oilfield N. It explores a single oil group, and intends it to be a guidance for similar exploration and an inspiration for research on low resistivity reservoir.

2. DEFINITION OF LOW RESISTIVITY RESERVOIR AND THE ANALYSIS OF ITS CAUSES

Generally, low resistivity reservoirs are those oil layers that have a low well logging response value, which cannot be easily distinguished from that of mudstone and aqueous layer, and that do not display apparent oil-gas characteristics. Virtually, when it comes to low resistivity reservoirs, there is a difference between relative low resistivity and absolute low resistivity. The resistance value of the majority of domestic oil layers ranges from 4 to 100$\Omega \cdot$m. Those whose value is below the minimum value are called low resistivity reservoir [2]. Hence, absolute resistivity refers to those whose value is below 4$\Omega \cdot$m, bordering that of mudstone and even aqueous layer. In addition, since the difference between the resistivity of different aqueous layers can be huge, and that an oilfield might consist of multiple aqueous layers, resistance enhancement rate is usually adopted to define low resistivity reservoir. Resistance enhancement rate is also called resistivity index, which refers to the ratio I between the resistivity of oil layer and layers near aqueous layer. Usually, oil layers whose $I<3$ are defined as low resistivity reservoir [3]. The standard varies according to the geological features and the layer.

Low resistivity reservoir has its own unique features in terms of depositional environment, lithological character, water affinity, clay property and pore structure. It can be seen that the main causes for low resistivity reservoir include highly mineralized formation water, high clay content, the development of micro-fracture, thickness. Low resistivity reservoir can be divided into 6 categories based on its formation mechanism: ① low resistivity reservoir with fine sandstone of double pore structure; ② low resistivity reservoir with fine sandstone rich in mud; ③ low resistivity reservoir with a low oil saturation; ④ low resistivity reservoir formed by highly-extremely mineralized formation water; ⑤ low resistivity reservoir with conductive minerals like pyrite; ⑥ low resistivity reservoir with highly porous fine sandstone [4].

3. LOGGING IDENTIFICATION OF LOW RESISTIVITY RESERVOIR

3.1 Identifying low resistivity reservoir by resistance enhancement rate

The Pearl River Mouth Basin is located on the edge of continental shelf in the north of the South Sea, and is an extensional basin with mainly Cenozoic fillings. Zhusan depression is located in the west of the basin, with an area of approximately 1.1×104km2. Its sub-tectonic units include Wenchang depression A, B, C, Qionghai depression, Yangjiang A depression, Qionghai convex and Yangjiang low convex, etc. Shenhu upheaval in the south, Hainan upheaval in the west, Yangjiang horst in the north constitute its boundary. Oilfield M is located on a palaeo-high developed upheaval in the middle of Paleogene. It is a oilfield with a neogene draping-anticline structure that is formed due to differential compaction on a background of basement Qianshan . Previous research proves Oil group ZJ1-4 of Oilfield M develops reservoir that is characterized by low resistivity, low permeability and strong anisotropy.

After analysis, it is found that the richness of mud is a main factor that influences the resistivity of reservoirs. Reservoirs in oilfield M main contain I/S mixed-layer, kaolinite, illite, and a small amount of chlorite, with a high concentration of clay mineral. And the content of clay is well correlated with the resistivity of wells (Figure 1). There is little pyrite, and it does not show a clear correlation with resistivity. Highly mineralized formation water is common in low-resistivity and high-resistivity reservoirs in the Pearl River Mouth Basin, whose influence on resistivity of oil layers is not remarkable. Its influence can be omitted.

That is to say, a high clay content is the main cause for low resistivity reservoir.

Based on the information of well logging and core data, Oil group ZJ1-4 of Oilfield M mainly develops: mudstone, argillaceous siltstone, siltstone and fine sandstone, and a small amount of grey fine sandstone in some areas. The electrical characteristics of various reservoirs are shown in Table 1, the statistical histogram of resistivity shown in Figure 2. The histogram shows that low resistivity reservoirs are the majority, with a resistance value below 2Ω·m. The resistance value of 70% reservoirs is below 4Ω·m.

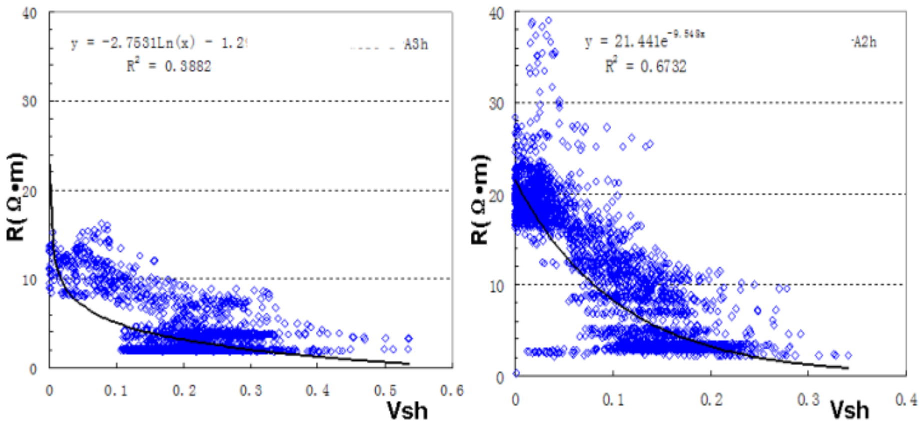

Figure 1. The relation between the richness of mud in Oil group ZJ1-4 of Oilfield M and resistivity

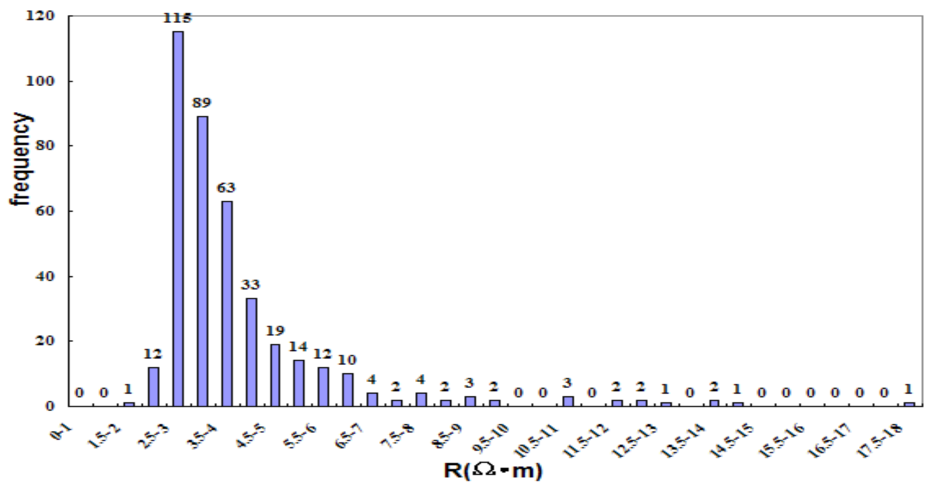

Figure 2. The histogram of resistivity of reservoirs in Oil group ZJ1-4 of Oilfield M

Table 1. The electrical characteristics of Oil group ZJ1-4 in Oilfield M

lithological character		Resistivity (Ω•m)		Density (g/cm³)	
		distribution range	mean	distribution range	mean
Oil layer	fine sandstone	5-11.99	7.6	2.13-2.44	2.32
	grey fine sandstone	3.88-17.92	8.3	2.18-2.39	2.28
	argillaceous fine sandstone	2.73-4.17	3.1	2.35-2.44	2.4
	siltstone	2.36-4.37	3.1	1.95-2.42	2.28
	argillaceous siltstone	2.69-12.27	4	1.98-2.34	2.27
Dry layer	fine sandstone	3.8-6.2	5.13	2.29-2.51	2.41
	grey fine sandstone	3.1-19.69	7.12	2.47-2.5	2.49
	argillaceous fine sandstone	2.74-3.21	2.95	2.36-2.48	2.44
	siltstone	1.16-5.12	2.56	2.21-2.48	2.39
	argillaceous siltstone	1.55-2.83	2.17	2.35-2.48	2.4

According to the physical property of aqueous layer, oil layer whose porosity is close to that of aqueous layer, as well as mudstone is chosen to define the resistivity index. Given that there are differences on the lithological character of layers in the area, analysis is conducted respectively on different lithological characters, as is shown in Table 2 and 3:

Table 2. Analysis of resistivity index of fine sandstone layer in Oil group ZJ1-4 of Oilfield M

lithological character	explanation	name	depth	Rt (Ω·m)	Φ (%)	I (oil/water)	I (oil/mud)
fine sandstone	High resistivity reservoir	5h	1869.9-1874.8	4.17	22.67	4	3.76
fine sandstone	aqueous layer	3	1268.5-1271.0	1.04	22.68		
mudstone	Mudstone	3	1280-1288	1.11			

Table 3. Analysis of resistivity index of siltstone layer in Oil group ZJ1-4 of Oilfield M

lithological character	explanation	name	depth	Rt (Ω·m)	Φ (%)	I (oil/water)	I (oil/mud)
siltstone	low resistivity reservoir	4h	1633.5-1674.3	2.45	22.1	2.8	2.2
siltstone	aqueous layer	2	1263.8-1268.3	0.87	22.68		
Mudstone	Mudstone	3	1280-1288	1.11			

Note: no standard aqueous layer is found in the siltstone layer in ZJ1-4 oil group, hence, aqueous layer from ZJ1-5 oil group is chosen as the reference for comparison.

Table 4. The electrical property of low resistivity reservoir in Oil group ZJ1-4 of Oilfield M

parameter	Rt (Ω·m)	P (g/cm^3)	I
Electrical property of low resistivity reservoir	2—4	>2.27	$2.2 \le I < 3.76$

After comprehensive analysis, the electrical property of low resistivity reservoir is shown in Table 4.

The exploration and the above research on the basic electrical characteristics of low resistivity reservoir prove that when geological features are taken into consideration, and that reasonable logging interpretation parameters are chosen, resistance enhancement rate can help a lot to identify low resistivity reservoir.

3.2 Improving the resolution of resistivity curve through frequency matching method

Oilfield N is located in the middle of a convex in Zhusan depression of the Pearl River Mouth Basin. The component analysis and size analysis of rock in the cored interval show that rocks in low resistivity reservoir of Oilfield N mainly include argillaceous and aleuritic fine sandstone, gritty siltstone, argillaceous siltstone, argillaceous siltstone and aleuritic mudstone, etc.

The comprehensive analysis of factors that contribute to the formation of low resistivity reservoir shows that the main reason for low resistivity of Oil group ZJ1 of Oilfield N is the high proportion of fine-micro pores, which further results in high irreducible water saturation. In addition, the widespread development of thin interlayer also has an influence because the resistivity is further lowered due to the surrounding rocks that have low resistivity. Particle size of this group is comparatively bigger, and fine sandstone is the majority. The richness of mud is relatively lower than other oil groups, hence, mud is the minor factor that contributes to low resistivity; the richness of siderite and pyrite in the work area is relatively lower, and low resistivity and high resistivity layers do not display salient difference in terms of the richness of siderite and pyrite. Conductive minerals have little influence on the low resistivity. Hence, when it comes to the development of thin interlayer of ZJ1 Group, frequency matching method［5、6］is used to improve the resolution of resistivity curve to interpret low resistivity reservoir.

The resolution matching of the well logging curve consists of two aspects: the first is to reduce the resolution of high-resolution curve to match low resolution curve; the second is to increase the resolution of low-resolution curve to match high-resolution curve［7］. Frequency matching method can find wide application, which does not require the response coefficient of well logging method ［8］. Frequency matching method can not only match low-resolution curve to high-resolution curve, but also vice versa. Frequency matching method can effectively analyze and remove the interference signal of well logging. One of its flaws is that there must be a high-resolution curve that the environment has little influence on; another is that the matching result is not good when it comes to severely expanded or intruded sections ［9］.The low-resolution resistivity curve that has been treated with frequency matching method can better reflect the information on the thin layer. Figure 3 is the 997~1005 meters section of Well 1 from Oilfield N. The horizontal range of the peak value from the resistivity curve whose resolution has been increase is remarkably enhanced.

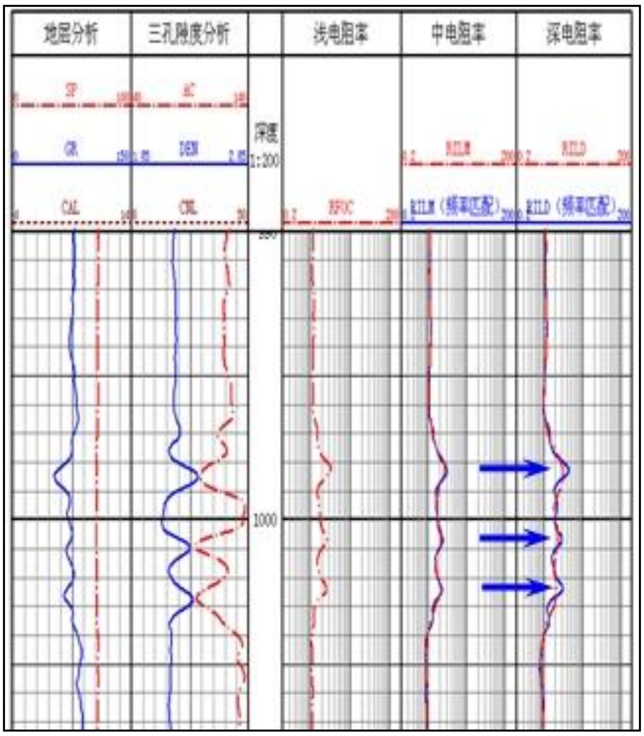

Figure 3. The improved resolution after frequency is large, which can help better identify the information of thin layer

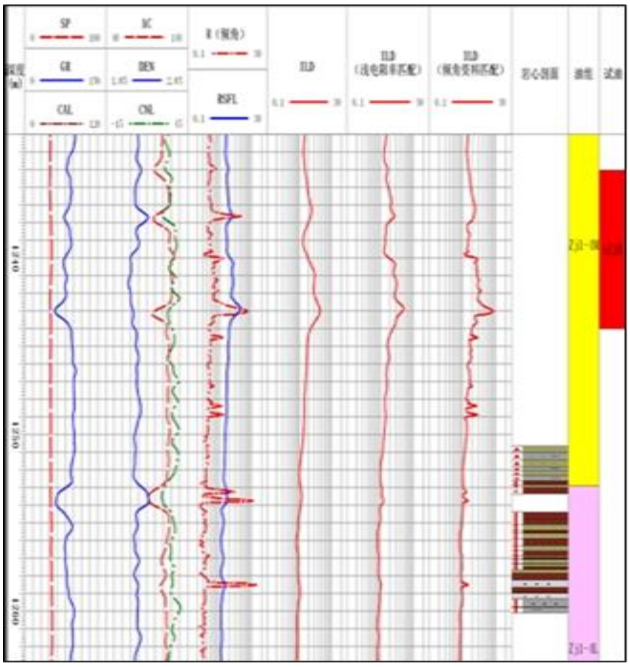

Figure 4. Comparison of high-resolution result of Section ZJ1, Well 1, Oilfield N

Information from dipmeter logging has better vertical resolution. The method can be used to render higher the vertical resolution of the deep resistivity curve that has been treated with frequency matching method [8]. Figure 4 shows that the result matched from dipmeter logging information is closer to the dipmeter-logging resistivity curve in terms of the shape. There exist many peak values and the horizontal range is large, which can help better identify the information of thin layer.

Rough statistical analysis of thin layers in the reservoir interval, namely the oil-containing section of the cored interval and the oil-testing interval (shown in Table 5), after comparison and analysis of deep resistivity curve and information from dipmeter logging, and taking into consideration the matching result of shallow resistivity curve, it is found that the information on thin-layer from the matching result of dipmeter logging is more clear. The layer that can be classified is thinner and the difference value of resistivity larger, which can help better identify and classify low resistivity reservoir.

Table 5. Analysis of thin layer with high resolution of Section ZJ1, Well 1, Oilfield N

No.	Top depth (m)	Bottom depth (m)	Thickness (m)	Deep resistivity (Ω•m)	Shallow resistivity matching (Ω•m)	Dipmeter Information matching (Ω•m)	Resistivity difference value(Ω•m)	Category of information	Oil occurrence
1	1253.12	1253.32	0.2	1.165	1.146	1.495	0.33	Core	Oil stain
2	1239.95	1240.31	0.36	2.068	2.325	3.23	1.162	well testing	
3	1241.73	1242.03	0.3	2.782	2.923	3.118	0.336	well testing	
4	1243.92	1243.99	0.07	2.338	2.546	6.115	3.777	well testing	
5	1068.14	1068.37	0.23	1.577	1.88	1.872	0.295	Core	oil patch
6	1273.4	1273.58	0.18	1.18	1.123	1.256	0.076	Core	rich in oil
7	1273.81	1273.96	0.15	1.142	1.065	1.274	0.132	Core	rich in oil
8	1275.11	1275.28	0.17	1.195	1.287	1.327	0.132	Core	oil patch
9	1275.41	1275.69	0.28	1.239	1.349	1.501	0.262	Core	oil patch
10	1275.74	1275.92	0.18	1.266	1.234	1.502	0.236	Core	oil patch
11	999.95	1000.3	0.35	2.188	1.997	2.502	0.314	well testing	
12	1087.58	1087.78	0.2	1.553	1.685	1.728	0.175	well testing	
13	1262.48	1262.79	0.31	2.387	2.824	2.545	0.158	well testing	

4. CONCLUSIONS

After the research on the basic electrical characteristics of low resistivity reservoir, when the geological features are taken into consideration, and that reasonable logging interpretation parameters are chosen, resistance enhancement rate can help a lot to identify low resistivity reservoir. After medium-deep resistivity curves are treated with and its resolution increased by frequency matching method, the horizontal range of the curve is remarkably enhanced, which helps with the research on thin interlayer. Through comparing and analyzing the deep resistivity curve of the thin layer in the cored interval and the matching result from dipmeter logging information, and taking into consideration the matching result of shallow resistivity curve, it is found that the information on thin-layer from the matching result of dipmeter logging is clearer. The layer that can be classified is thinner and the difference value of resistivity larger, which can help better identify and classify low resistivity reservoir.

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