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Study on Main Controlling Factors and Fluid Identification Methods of Low-resistivity Reservoirs based on BP Nerve Network Verification in X Area of Ordos Basin

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Abstract: - The low-resistivity oil layers refer to a formation whose resistivity response is opposite to the typical oil layers and similar to water layer. Distinguishing it from water layer in logging interpretation is very difficult, which brings great difficulties to oil and gas exploration and development. The exploration and development research shows that there is obvious resistivity anomaly in X area of Ordos Basin, and typical low-resistivity oil layers are developed in formation A in this area, so it is difficult to accurately divide oil layers and water layers only from logging response. In order to identify the fluid properties in low-resistivity oil layer areas, based on conventional logging data of formation A in X area, through petrophysical experimental analysis, combined with formation water analysis data, logging, oil test and other data, the main control factors of low-resistivity oil layers in X area are deeply studied in many aspects, and a more effective fluid identification method is put forward by combining the secondary evaluation of porosity and permeability and the flow unit method. The BP nerve network simulation cross plot is used to verify the identification results. The research shows that the main control factors of low resistivity oil layers in the study area are related to the salinity of water and pore connectivity, and also to the lithologic properties of different formations. Based on the study of the main control factors of low-resistivity oil layers, a multi-factor fluid identification method is proposed. The coincidence rate between the evaluation results of this identification method and oil test is 85.7%, which can identify the oil-water reservoirs in X area more effectively and accurately, finally identify the location of low-resistivity oil layers and boost the growth rate of oil and gas production.

Keywords: High Resistivity Water Layers; Low Resistivity Oil Layers; Main Control Factors; Fluid Identification Method; BP Nerve Network; Ordos Basin

I. Introduction

Low-resistivity reservoirs are important subtle oil and gas reservoirs, which are widely distributed in China, and are the most potential targets for oilfield review and storage increase [1-2]. Resistivity logging curve is an important curve to preliminarily judge the properties of formation fluid by using logging data. From the resistivity curve, the resistivity value of low-resistivity oil layer is opposite to that of conventional oil layer, and it has nearly the same low resistivity as that of water layer [3]. The resistivity anomaly of low-resistivity oil layers makes it more difficult to identify oil-water layers. It is of great significance to study the main control factors and fluid identification methods of low-resistivity oil layers for increasing oil and gas reserves and production.

For the main control factors of low-resistivity oil and gas reservoirs, many scholars have done some related research. Sun Jianmeng [4], Xu Jinxiu [5] et al attributed the low resistivity to the additional conductivity of clay minerals and the conductivity of low resistivity minerals such as pyrite in the formation. Yang Jiao,

Wang Weibin [6-7] et al found that the reservoir pore structure has a great influence on the irreducible water saturation, which results in the increase of irreducible water saturation and the formation of low-resistivity oil and gas reservoirs; Luo Shuiliang [8] et al thought that lithology, clay content and irreducible water saturation in low-resistivity oil and gas reservoirs are the main influencing factors of low resistivity, and formation water salinity and pore structure can also reduce the resistivity of oil and gas reservoirs to certain extent; Wu Jinlong [9] et al summarized the influence of macro-geological control factors of the micro-genetic mechanism in low-resistivity oil layers; Wang Jinmin [10] et al have studied the influence of different pore throat combinations on oil layers resistivity, and found that there is a situation that pore throat combinations will form low resistivity of reservoir; Yang Yi [11] et al studied the contribution of the additional conductivity and microstructure connectivity of clay minerals to the low resistivity of oil layers. Previous studies have showed that there are many main control factors in the formation of low resistivity oil layers, and there are great differences in different regions. On the basis of BP nerve network, Liang Limei [12] designed a nerve network simulation intersection chart that can be applied to identify the low-resistivity oil layers by comprehensively considering various factors such as reservoir lithology,

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physical properties, fluid conductivity and reservoir space. It has a high recognition rate and can be used to verify the fluid identification method.

Based on the well logging and oil test data, there are a large number of low-resistivity oil layers in formation A in this area, and the resistivity characteristics are contrary to those of conventional oil layers. In order to accurately distinguish the oil-water layers in X area from the logging response and analyze the main control factors of the oil-water layers with abnormal resistivity in X area, a fluid identification method of X area containing low-resistivity reservoirs is proposed to complete the effective identification and logging evaluation of oil-water layers. The BP nerve network simulation intersection chart is used to verify the results. It plays an important role in the development of logging interpretation methods for low-resistivity oil layers and improve oil and gas production in X area of Ordos Basin

II. General Situation Of Study Area

Area X is located in the southwest edge of Ordos Basin, and structurally belongs to Gucheng nose uplift on the slope of northern Shanxi. Formation A is divided into layers A1, A2 and A3 from top to bottom. The lithology of formation A is mainly lithic feldspar sandstone, and the intergranular pores and feldspar dissolved pores are the main pore types, with a small amount of intergranular dissolved pores and cuttings dissolved pores. Reservoir porosity is mainly distributed between 10% and 15%; The main distribution range of permeability is 0.2-6mD, belonging to low porosity and ultra-low permeability tight reservoir, in which A1 has an average porosity of 12.61% and an average permeability of 5.45md; A2 has an average porosity of 11.79% and an average permeability of 4.13md; A3 has an average porosity of 11.14% and an average permeability of 3.00md. Based on the capillary pressure curve obtained by mercury injection experiments on cores from 4 wells in formation A, it can be known that the pore throat structure of this reservoir is mainly medium sized pore to small pore to small throat.

Formation A in X area mainly develops low-resistivity oil layers. take well Z346 in formation A as an example, well Z346 is a typical low-resistivity oil layer, and the oil test results in the interval of 1237-1239m are oil layers, with a resistivity of 9.88Ω, which is much lower than that of conventional oil layers and almost the same as that of water layers, and it is a typical low-resistivity reservoir, as shown in Figure 1.

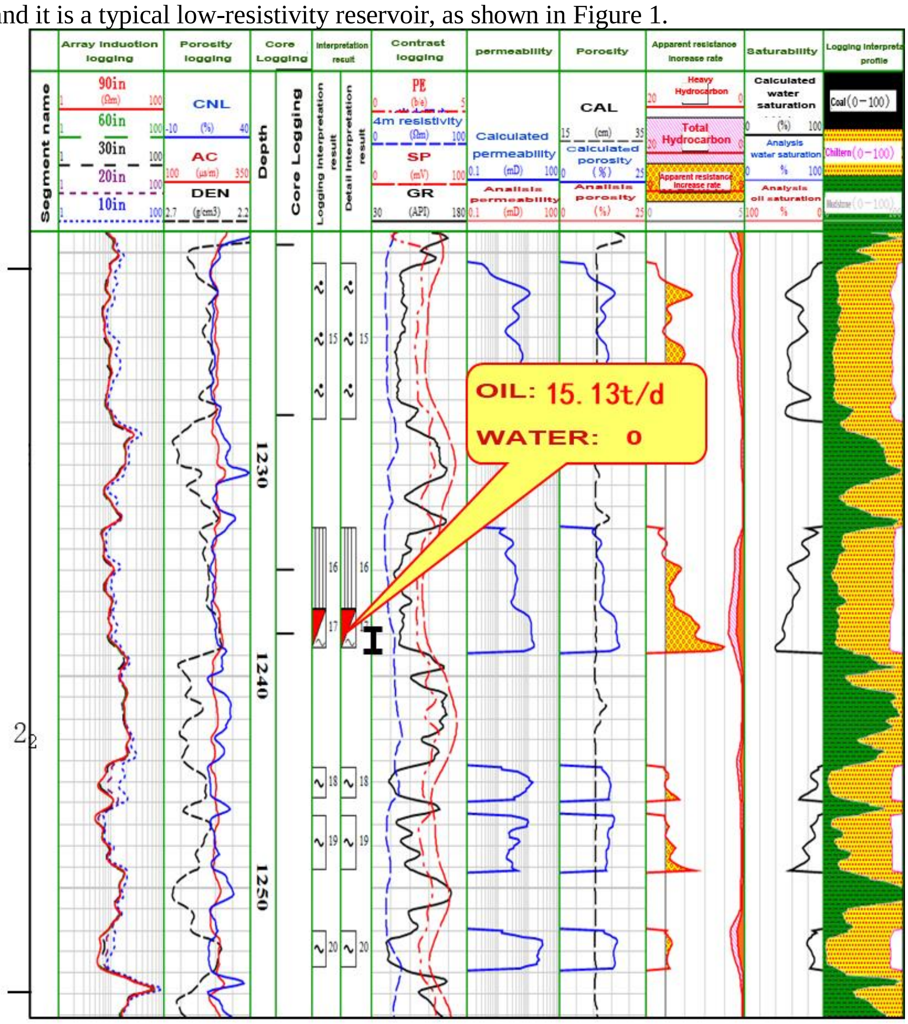

Figure. 1 Typical Low Resistivity oil layer, well Z346

III. MAIN CONTROL FACTORS OF LOW RESISTIVITY OIL LAYERS

The Ordos Basin contains a large number of low-resistivity oil layers, and the main control factors of the formation of low-resistivity oil layers are different in different regions. In order to derive the main control factors of low-resistivity oil layers in X area, combining with petro-physical experiments and logging data, the genetic mechanism of low-resistivity oil layers is clarified from the aspects of fluid properties, occurrence state, diagenetic minerals and logging array trend. The Study found that the main control factors for the formation of low-resistivity oil layers in formation A are: high salinity of formation water; high water saturation, high proportion of irreducible water saturation; pore connectivity is high (array induction is easy to form a highly connected annular ion flow), suitable for low resistance mineral skeleton composition and high argillaceous content.

A. Influence of Formation Water Resistivity on Resistivity of Oil Layers

According to the oil testing data, electrical properties and water analysis data of three wells from formation A in X area, as shown in Table 1, it shows that the average salinity of formation water in formation A has reached more than 50000ppm, and the salinity of water in oil layer is even much higher than that in water layer. In general, the values of chloride ion and salinity in the reservoir show that the oil layers are much higher than that in the water layer. When the salinity of the oil layer is higher than that of the water layer, the difference in resistivity between the oil layer and the water layer will decrease, and with the expansion of the difference in salinity and resistivity will become smaller and smaller, leading to the formation of low-resistivity oil layers, which makes it very difficult to identify oil-water.

Table 1 A formation water analysis data of three wells in formation A

Well	Oil testing conclusion	Resistivity (Ω.m)	Salinity (mg/L)
b67	Oil-water layer	10.61	70103
l10	water layer	11.56	58442
b47	Oil layer	11.86	66406.9

B. Influence of Water Saturation on Reservoir Resistivity

By analyzing the fluid-bearing properties and fluid content of formation A and three sub-layers, it can be seen that the overall oil content of formation A is below 20%, and the water saturation is about 80%, of which the bound fluid exceeds 40%, and the bound fluid in sandstone interval is basically water. According to the relationship diagram between bound water saturation and resistivity, it can be seen that high bound water saturation in low resistivity oil layers is an important reason for low resistivity.

C. Influence of Pore Connectivity on Resistivity of Oil Layers

Based on the analysis data of core physical properties, the distribution histogram of porosity and permeability in formation A is fitted, and the porosity and permeability range are summarized in small layers. It is found that the average porosity and permeability of layer A are 14% and above 10mD , as shown in Table 2. It shows that the shale with high pore connectivity and bound water can be interconnected, and can form ion flow under induction logging, with high conductivity.

Table 2 Layered range of porosity and permeability in formation A

Layers	Porosity			Permeability		
	Main formation(%)	Concentration formation(%)	Average value(%)	Main formation($\times10^{-3}$ μm^2)	Concentration formation($\times10^{-3}$ μm^2)	Average value($\times10^{-3}$ μm^2)
A1	8-18	11-17	13.49	0.01-100	0.10-50	6.93
A2	7-19	11-18	13.19	0.01-200	0.01-100	26.74
A3	10-18	12-17	14.53	0.01-100	0.70-50	14.89

D. Influence of Shale Content on Formation Resistivity

According to the logging analysis data, it is found that the spontaneous potential logging curve shows a large degree of negative anomaly, and the formation water has high salinity and strong conductivity. Taking well b98 as an example, the nuclear magnetic logging analysis of the oil testing oil layer section shows that the oil saturation of this interval is about 18%, while the water saturation is about 82%, in which the irreducible water accounts for more than 90%. Moreover, the overall natural gamma logging value of this interval is relatively high, and the average value can reach 50% of that of the pure mudstone interval, indicating that this interval has the argillaceous conditions for enriching bound water.

IV. Identification Method Of Formation Fluid With Abnormal Resistivity

The identification methods of low-resistivity oil layers formed by different main control factors are different. The existing identification methods of low-resistivity oil layers include the chart method based on logging curves, the shift spectrum method based on fluid properties, the model calculation method and the direct comparison method of resistivity and et al. All these methods have strong regional characteristics and have not established a set of comprehensive fluid identification methods that integrate the influence of various factors. Therefore, in order to establish a comprehensive multi-factor and all-round method to identify fluid properties for low-resistivity oil layers in X area, a comprehensive method to identify fluid properties from three aspects, such as porosity and permeability, flow unit index, two kinds of apparent water saturation and conventional logging curves, is proposed.

A. Identify Dry Layer by the Cross Plot Of Porosity and Permeability and the Index of Fluid Unit.

For formation A, the porosity and permeability calculation formula of three layers is obtained by secondary fitting of core porosity and logging data layers and core porosity and permeability fitting. Based on the porosity and permeability calculation formula of layered section, the average porosity and permeability of water layer, oil layer, dry layer and oil-water layer in several wells in formation A are intersected, and the intersection scatter diagram shows that the dry layer is obviously different from other fluid properties strata, and the dry layer can be divided according to the porosity and permeability characteristics, as shown in Figure 3.

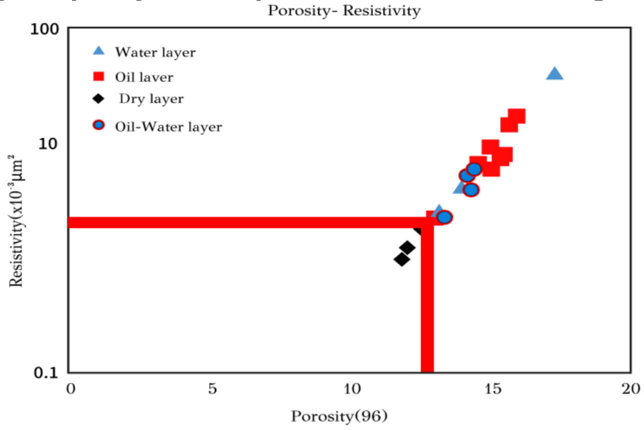

Figure. 3 Scatter diagram of porosity-permeability cross plot (the part below the red line is the dry layer area)

According to the theory of flow unit, the flow unit index FZI is also one of the methods for identifying formation fluids. When calculating the flow unit index of multiple wells in formation A containing different fluids, it is found that there are obvious differences between the dry layer and other fluid-bearing formations, so the flow unit index can be used as the second index for identifying the dry layer. It can be seen that when FZI is less than 0.08, all scattered points in the area belong to the dry layer, as shown in Figure.4. Finally, combining the cross plot of porosity and permeability and the index cross plot of resistivity flow unit, the fluid property division table 3 is put forward, in which the division of dry layer is the most clear, and the division of other fluid-bearing strata has overlapping parts, so the cross plot of porosity and permeability and FZI can only be used for the clear division of dry layer.

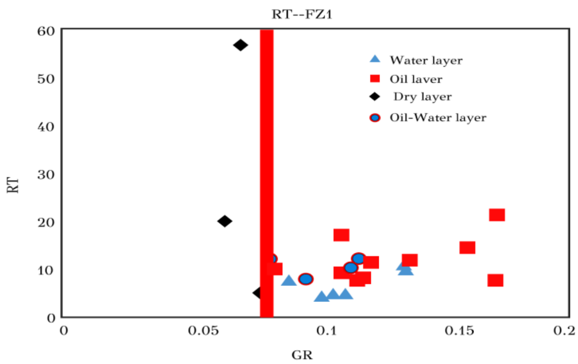

Figure. 4 Cross plot of resistivity-flow unit index (dry layer area on the left of red line)

Table 3 Porosity and permeability cross plot and FZI dry layer division table

Formation A	Porosity	Permeability	FZI
Oil layer	>13	>6	>0.1
Water layer	>12.5	>2.5	>0.1
Oil-water layer	>12.5	>2.5	>0.08
Dry layer	<12.5	<2.5	<0.08

B. Plate Method

According to the existing oil testing data and logging data, it can be combined with resistivity logging, natural gamma logging, compensated density logging and interval transit time logging data for intersection, and combined with multi-parameter comprehensive evaluation. Construct the resistivity increase index I, density resistivity relative value index and mudstone baseline deviation index SHD cross plot for further evaluation. The oil layer and water layer of formation A are divided, and the established oil-water layer division chart is shown in Figure. 5.

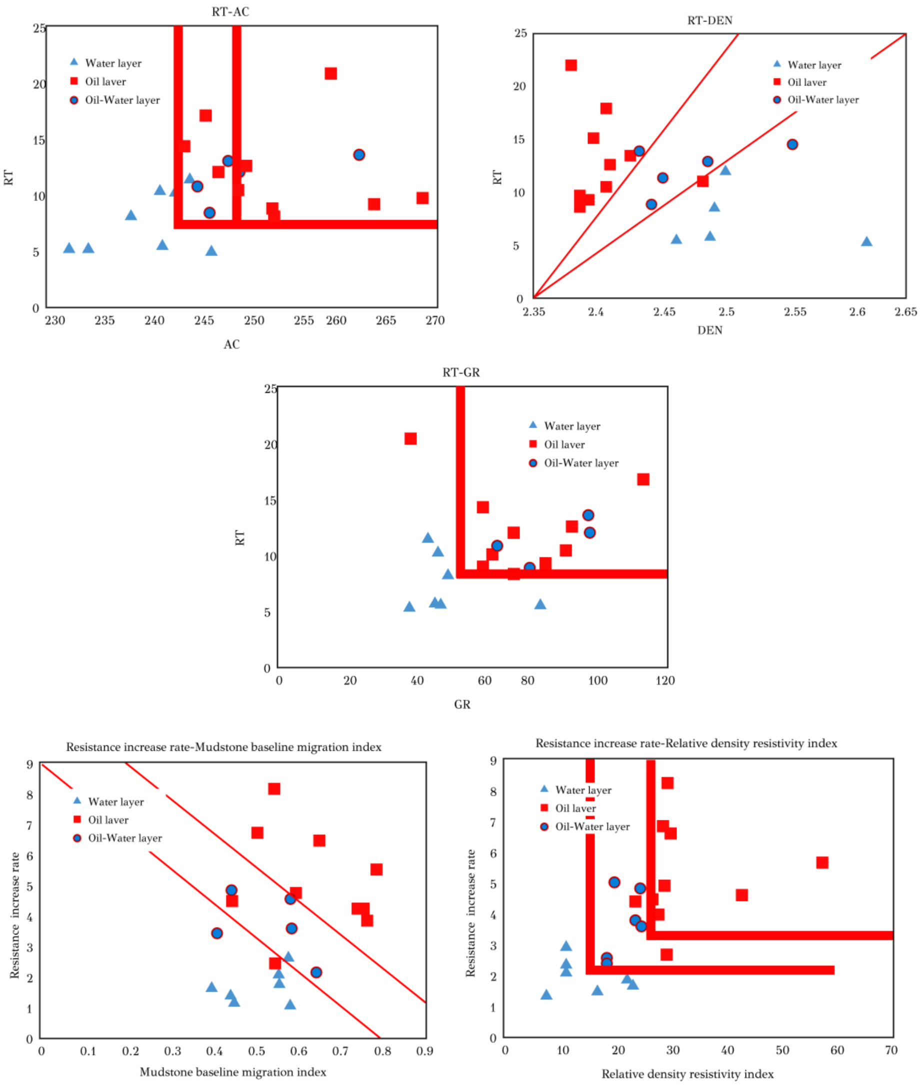

Figure. 5 Shows the cross plot of relative values of RT-AC, RT-DEN, RT-GR, I-SHD and I- density resistivity in turn.

Based on the above analysis, in order to solve the problem that identify the low-resistivity oil layers in formation A is very difficult, distinguish the reservoir and the dry layer by the pore-permeability intersection diagram and the flow unit method, and then identify the oil layer, water layer and oil-water layer by the double Rw intersection comparison method and the chart method, combine all those methods to finally form the following fluid identification method for formation A, as shown in Table 4.

Table 4 Reservoir A fluid identification standard

Reservoir A fluid identification	Oil layer	Oil-water layer	Water layer	Dry layer
Porosity (%)	POR≥13			POR≤12.5
Permeability(md)	K≥3			K<2.5
Flow unit index FZI	FZI≥0.08			FZI<0.08
acoustic time difference(μs/m)	AC≥245	245<AC<250	AC≤245	
Natural gamma(API)	GR>60		GR<80	
Density(g/cm^3)	DEN<2.42	2.5>DEN>2.42	DEN>2.45	
Relative values index of density resistivity	>30	20-30	<20	
Resistance increase rate index	>3	2-5	<2.5	

V. APPLICATION OF FLUID IDENTIFICATION METHOD

This paper proposes the fluid identification method used to interpret the oil and gas of 39 wells in the study area. The results are compared with the oil test results. It is found that 85.7 % of the interpretation results of this method are coincident with the oil test results, indicating that the results of the second interpretation of the fluid identification method are reliable. The interpretation results of this method and the oil test comparison table of 18 wells in the study area are shown in Table 5.

Table 5 Second interpretation and oil test comparison table

Well	B269-64	B285-56	B287-581	B297-50	B303-47	B79	B97	B98	H43-53	H39-61	L3	N12-30	M137	N138	N139	N158	N41	N216
Top depth	2014	2034	1912	1846	1902	1370	1924	1710	1852	1824	1798.5	1863	1730.5	1145.5	1782	1735	1679.1	1339
Bottom depth	2022	2039	1918	1853	1908	1372	1927	1719	1836	1828	1824	1868	1745	1146.5	1802	1738	1681.1	1340
Daily oil production Oil test(t/d)	8.67	0.3	24	19.2	0.02	1.36	21.25	0.85	3.3	20.4	116.02	13.4	0.1	21.76	0.1	0.1	1.36	41.65
Daily water production of oil test(m3/d)	17.2	9.4	0	6.6	18	30.5	0	7.4	0	0	0	6.2	5.2	0	25.1	5.3	0	0
Oil test conclusion	Oil-water layer	Water layer	Oil layer	Oil-water layer	Water layer	Oily water layer	Oil layer	Oily water layer	Weak oil layer	Oil layer	Oil layer	Water layer	Water layer	Oil layer	Water layer	Water layer	Weak oil layer	Oil layer
Conclusion based on this method	Oil-water layer	Water layer	Oil layer	Oil-water layer	Water layer	Oil-water layer	Oil layer	Oily water layer	Oily water layer	Oil layer	Oil layer	Oil-water layer	Water layer	Oil-water layer	Oily water layer	Oily water layer	Weak oil layer	Oil layer

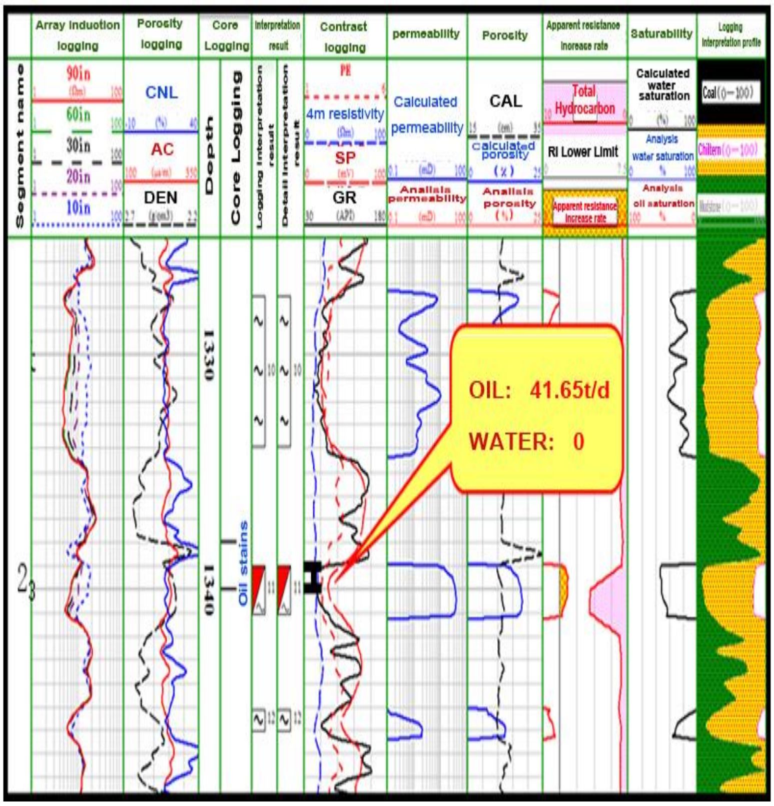

Figure. 6 N216 well 1339-1340 m logging results and oil test results.

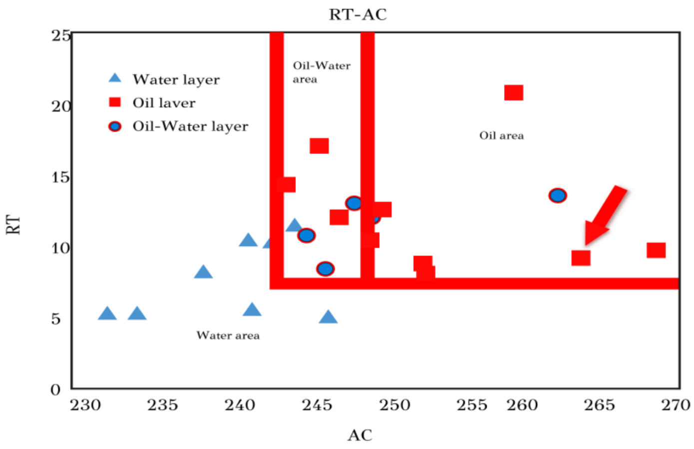

Figure. 7 RT-AC chart (the point indicated by the red arrow is the projection point of N216 logging data)

Taking N216 well as an example, the average reservoir resistivity is 8.64 Ω · m, and the acoustic time difference is 253 μs · m-1. The common interpretation conclusion is the oil-water layer. The analysis of reservoir characteristics shows that GR and compensated neutron response show that the reservoir has higher shale content, lower density response value and higher porosity. Compared with the adjacent water layer of this well, the physical properties are better.The adjacent water layer is not selected as the comparison layer, and the RT-AC chart is put in the water layer area, which is consistent with the oil test conclusion as shown in Figure. 6 and Figure. 7.

The BP nerve network crossplot is used to discriminate the logging data corresponding to the reservoir section of 18 wells. The results as shown in Figure.8 are basically consistent with the discriminant results of the method in this paper, and the correspondence is good. It shows that the identification method in this paper can well discriminate the fluid type. It has certain universality and can be applied to the identification of low-resistivity oil layers formed by different main controlling factors.

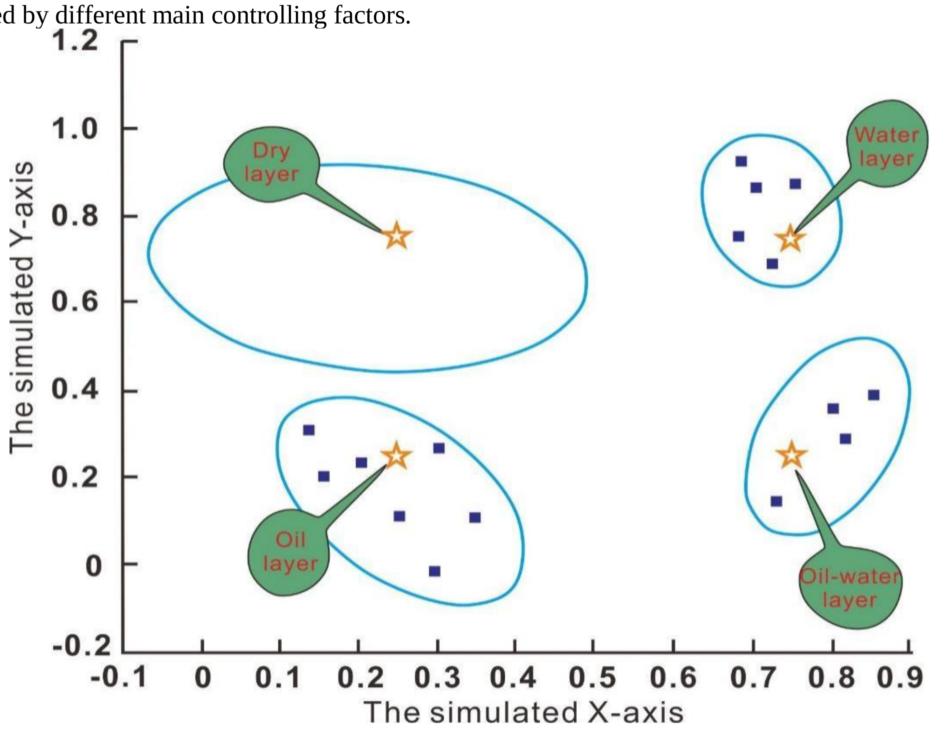

Figure. 8 The distribution map of the test results on the crossplot

VI. Conclusion

Through the analysis of the main controlling factors of the formation of low resistivity oil layer in X area of Ordos Basin, the fluid identification method of the resistivity abnormal wells in this area is proposed, the following conclusions were drawn:

There are five main factors for the low resistivity oil layer formed in formation A in Region X: High formation water salinity; High water saturation, and a high proportion of bound water saturation; High pore connectivity (array induction easily forms highly connected circular ion flow); Suitable for low resistance mineral skeleton composition; High mud content.

Through analyzing the main controlling factors of the low-resistivity oil layer of formation A and Regarding the main controlling factors for the formation of abnormal resistivity, combined with penetration cross plot method, fluid element index method, double Rw cross plot comparison method, plate method, array induction gradient factor method and nuclear magnetic method, the classification of reservoir fluid properties in different reservoirs and different strata was studied. A fluid identification method for formation A is presented. This method was used to identify reservoir fluids from 39 Wells in Area X. The coincidence rate between the interpretation results and the oil test results is as high as 85.7%, The results are consistent with the BP nerve network intersection diagram. which can comprehensively and effectively distinguish the Oil-gas-water reservoir in X area, to realize the identification of low resistance oil layer, so as to promote the increase of oil and gas storage and production in this area.

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