

A Method for Identifying the Light Oil Layer and Condensate Gas Layer Based on the Distribution of Heavy Hydrocarbon Components

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Abstract: There are limitations in using traditional gas logging interpretation to identify oil and gas layers containing light oil and heavy gas, and accurate identification techniques are urgently required. We chose the Xihu Sag as an example to demonstrate the method. Large amounts of gas logging data were analyzed and the critical trend lines of heavy hydrocarbon components in the oil and gas layers were established. The results showed obvious differences between the distribution characteristics of the hydrocarbon components of the oil and gas layers. When the gas-oil ratio of the gas layer was higher, the light hydrocarbon content was higher, and the proportion of heavy hydrocarbon components was lower. In contrast, when the gas-oil ratio of the oil layer was lower, the heavy hydrocarbon content was higher, and the proportion of the heavy hydrocarbon component was higher. A hydrocarbon component chart analysis showed that when the hydrocarbon component distribution curve was more concentrated, the heavy hydrocarbon content was lower. The gas and oil layers were distributed within and outside of the critical line. The gas logging interpretation results of 25 wells in the study area showed that the interpretation coincidence rate of the hydrocarbon component distribution method was 89.5%, 10% higher than that of the traditional gas logging method. This method solves the problem of identifying complex fluids to a certain extent and is thus of great significance for reducing the cost of developing oil and gas fields and formulating reasonable developmental strategies.

Keywords: Xihu Sag, Light Oil, Condensate Gas, Hydrocarbon Components, Critical Line

1. Introduction

There are huge reservoirs within the low permeability reservoir of the Xihu Sag, which is the main exploration area within the Xihu continental shelf basin in the East China Sea. The Pinghu, Tianwaitian, other oil and gas fields, and hydrocarbon-bearing structures have been discovered in this region after years of exploration [1]. However, with an increase in the exploration intensity, the area of exploration now encompasses diverse and deeply buried reservoirs with poor physical properties, and it is important to identify the fluid properties therein [2-4] to formulate appropriate development technology [5-8].

There are many methods and techniques for fluid identification, which can be qualitatively or quantitatively achieved at different stages and costs of well location implementation. As shown in Figure 1, gas logging is the

lowest cost and real-time first-hand data during the drilling phase, which can intuitively reflect the information of the original formation fluid; Logging is widely used in fluid identification. Due to factors such as reservoir formation water salinity, rock conductive mineral content, mud invasion, and reservoir pore structure, difficulties are often encountered in interpreting some low resistivity oil and gas reservoirs, special lithology oil and gas reservoirs, and condensate gas reservoirs with high volatile oil to low gas oil ratios [9-10]. Testing and production are reliable means of quantitatively distinguishing fluid properties, but their cost is high and they are at the end of well site implementation, which has a certain restrictive effect on the formulation of development technology policies. Gas logging data are complete and can be obtained at a low cost compared to logging data, and they can therefore be used to identify fluid properties [11].

However, the Xihu Sag contains oil and gas with light oil and

condensate gas characteristics, and it is difficult to distinguish the fluid using gas logging interpretation methods [12]. Traditional gas logging interpretation methods, such as the Pixler hydrocarbon ratio method, triangle chart method, and hydrocarbon humidity ratio method (also known as the 3H method) [13-15] are useful for recognizing typical oil and gas layers, but they have certain inherent limitations (Table 1). The establishment of a gas logging intersection chart is closely related to the characteristics of the formation fluid, and different oil fields have different charts that are only applicable to the particular field and its adjacent areas. The scope of application is not universal, especially with respect to the identification of light oil layers and condensate gas layers. Therefore, it is urgent to explore and establish new interpretation methods in this area to improve the coincidence rate and applicability of interpretation.

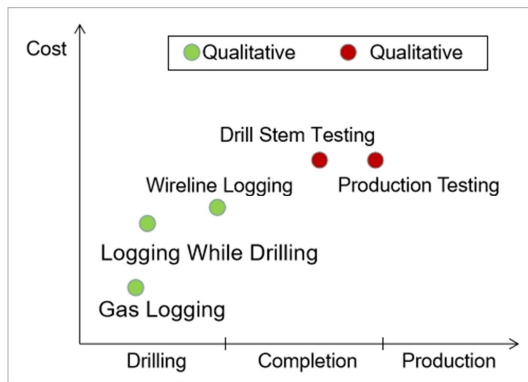


Figure 1. Comparison of Fluid Identification Methods and Data Collection Costs at Different Stages.

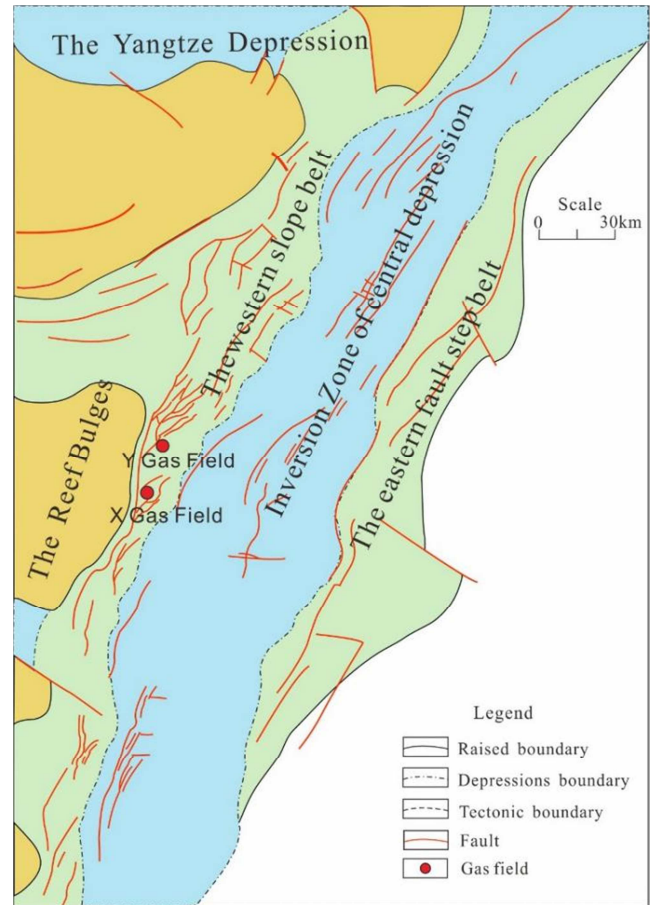


Figure 2. Regional Structural Map of the Xihu Sag.

Table 1. Conventional Gas Logging Interpretation Method.

Method	Features and parameters	Limitation	Reference
Pixler hydrocarbon ratio	C_1/C_2 , C_1/C_3 , C_1/C_4 ratio to establish standard chart	1. A large number of data samples are needed; 2. The data display is not intuitive; 3. It is difficult to identify light oil.	David et al.; Song, et al., 1999; Yu, et al., 2013 [14, 16-17]
Hydrocarbon humidity ratio	Establishment of standard charts for hydrocarbon humidity ratio, hydrocarbon equilibrium ratio, and hydrocarbon characteristic ratio	The discrimination accuracy of volatile oil layers and condensate gas layers is low.	Huang, 2007; Chen, et al., 2020; Hu, et al., 2009; Yan, et al., 2020; Zhang, et al., 2020 [18-22]
Triangle chart	A triangular chart is established based on the three parameters: $C_2/\sum C$, $C_3/\sum C$, and $C_4/\sum C$ ($\sum C$: $C_1 + C_2 + C_3 + C_4$)	1. Ignores heavy hydrocarbon information, such as that pertaining to C_5 ; 2. It has certain applicable conditions, and different geological backgrounds have different statistical laws.	Plock and Kloft, 2005; Darvesh, et al., 2011; Hou, et al., 2009; Song, et al., 2009 [23-25]

In this study, the differences between the composition of well flow in oil and condensate gas layers with different gas-oil ratios and the gas logging components of the gas and oil layers in oil and gas production fields were analyzed. Using the test and production layers in the production oil and gas fields as a reference, the critical trend line of gas layers and a standard chart for oil and gas layers in this area was established, and the suitability of using the gas logging interpretation method in the Xihu Sag was determined. The method employed here directly uses first-hand drilling data to quickly identify the fluid and thus provides a rapid response. It is also convenient to use at a low cost and is of great significance for the development of offshore oil and gas fields,

for which there are fewer available drilling data.

2. Regional Background

The Xihu Sag is located in the middle of the eastern depression belt of the East China Sea shelf basin (Figure 2), which is rich in oil and gas resources. To date, the Pinghu, Kongqueing, other oil and gas fields, Yuquan and Qiuyue have been found [26], and the area is the main battlefield of exploration and development in the East China Sea. The sedimentary Xihu Sag was developed in a late Cretaceous tectonic setting. The Cenozoic sedimentary strata from bottom to top are mainly related to the Eocene Pinghu Formation, the

Eocene Pinghu Formation, the Oligocene Huagang Formation, the Miocene Longjing Formation, the Yuquan Formation, the Liulang Formation, the Pliocene Santan Formation, and the Quaternary Donghai Group. Oil and gas are mainly distributed in the Eocene Pinghu Formation (P) and the Oligocene Huagang Formation (H), and the reservoirs are developed at burial depths of 2500 m to 4500 m [27-28]. There are four types of crude oil in the structural belt: normal condensate oil, abnormal condensate oil, light crude oil, and normal crude oil. The natural gas produced is mainly condensate gas with a pyrolysis origin, and the oil and gas produced are mainly condensate gas, followed by crude oil [29].

3. Data and Methods

3.1. Data

X and Y are oil and gas production fields in the Xihu Sag; drilling data are rich, and the gas logging components are

complete (Table 2). Testing and production data have confirmed the existence of fluid, and they show the development of light oil layers and low gas-oil ratio condensate gas layers in both oil and gas fields. The light oil layer is light in color (orange-red, soy-sauce color), with a density of (0.668–0.853) g/cm³ and a gas-oil ratio of (1–400) m³/m³. The condensate oil in the condensate gas layer is colorless to orange-red, with a density of 0.631–0.738 g/cm³ and a gas-oil ratio of 2000–10000 m³/m³. The gas logging data show that the oil and gas layers have C₁ contents of 70.43% to 92.41% and 79.76% to 90.09%, C₂ contents of 1.39% to 11.06% and 3.09% to 8.09%. From a numerical perspective, there is no significant difference in the values of C₁ and C₂ between oil and gas reservoirs. The physical properties and logging characteristics of the light oil and condensate gas layers, therefore, have certain similarities, and this increases the identification difficulty.

Table 2. Gas Logging Component Characteristics of X and Y Gas Field Development Wells in Xihu Sag.

Gas field	Reservoir type	Well	Layer	Depth	Density	Gas component (%)						
				m	g/cm ³	C ₁	C ₂	C ₃	iC ₄	nC ₄	iC ₅	nC ₅
X	Gas	X2	B12	3574.0	0.712	85.18	6.13	3.59	0.76	0.99	0.42	0.35
			B11	3379.5	0.681	87.89	5.15	2.77	0.72	0.54	0.21	0.11
			B7	3132.0	0.693	86.20	5.58	3.13	1.12	0.69	0.34	0.20
		X1	B4	3134.2	0.725	87.94	6.98	3.52	0.25	0.21	0.08	0.05
			B1	2978.5	0.719	85.00	6.96	3.61	0.94	0.74	0.34	0.16
			B12	3396.7	0.631	90.09	4.64	1.78	0.40	0.36	0.15	0.10
		X3	B10	3142.2	0.652	87.94	5.10	2.56	0.71	0.58	0.21	0.11
			B8	3379.5	0.707	82.50	7.22	4.17	1.06	0.88	0.27	0.10
			B6	3175.0	0.738	84.55	6.09	3.18	0.90	0.56	0.20	-
		X4	B4	3085.0	0.7	83.50	7.24	3.88	1.23	1.01	0.45	0.16
			B3	3009.8	0.725	85.49	6.41	3.13	1.10	0.76	0.16	-
			B1	2903.0	0.695	81.94	8.09	4.87	1.56	1.13	0.28	-
		X5	B11	3695.0	0.699	82.07	6.71	3.30	1.15	1.09	0.39	0.24
			B10	3541.2	0.711	80.70	8.17	3.31	1.13	1.19	0.41	0.27
			B8	3402.2	0.728	79.76	8.09	3.50	1.37	1.33	0.58	0.43
			B3	3031.0	0.713	80.49	7.78	3.08	1.38	1.09	0.50	0.30
	Oil	X2	A4	2629.0	0.794	84.89	3.30	2.07	3.31	1.52	1.08	0.29
		X6	A4	2610.0	0.820	62.86	4.73	4.19	9.97	5.99	4.76	1.97
		X1	A2	2314.0	0.678	92.41	2.16	0.64	0.43	0.26	0.66	0.25
			A7	2778.3	0.853	70.43	11.06	8.91	3.40	2.33	1.03	0.55
			A6	2708.6	0.759	83.86	5.84	2.76	1.48	0.97	0.80	0.47
		X4	A3	2372.5	0.718	89.56	1.48	0.38	1.10	0.72	0.72	0.42
			A2	2300.5	0.668	91.63	1.39	0.32	0.22	0.18	0.24	0.14
		X5	A6	2703.2	0.768	75.37	8.49	4.04	2.60	1.31	1.18	0.88
	Gas	Y1	B8	4150.2	-	95.40	3.74	0.71	0.09	0.07	-	-
		Y2	B6	3975.2	-	96.32	3.09	0.50	0.05	0.04	-	-
Y	Oil	Y3	B4	3875.7	-	93.22	4.97	1.32	0.33	0.15	-	-
		Y4	B3	3628.1	-	90.47	6.91	1.91	0.50	0.21	-	-
		Y5	B3	3424.0	-	94.44	3.61	1.50	0.28	0.17	-	-
			B3	3429.0	-	94.45	3.61	1.49	0.28	0.18	-	-

3.2. Methods

3.2.1. Data Normalization Processing

Due to the different drilling and completion conditions, gas logging measurement instruments, and reservoir characteristics, gas logging data differ between different well numbers, horizons, and oil and gas layers. Therefore, the data

were normalized to obtain the relative content of each component, with the aim of characterizing the differences between components. To differentiate between the light oil layer and the condensate gas layer in the study area, the data analysis focused on the heavy hydrocarbon component content.

The following formulas were used:

$$C_1\% = C_1 / \sum_{i=1}^{i=4} C_i, \quad (1)$$

$$C_2\% = C_2 / \sum_{i=1}^{i=4} C_i, \quad (2)$$

$$C_3\% = C_3 / \sum_{i=1}^{i=4} C_i, \quad (3)$$

$$C_4\% = C_4 / \sum_{i=1}^{i=4} C_i, \quad (4)$$

where C_i is a hydrocarbon with i carbon atoms, C_1 is a hydrocarbon with 1 carbon atoms; C_2 is a hydrocarbon with 2 carbon atoms; C_3 is a hydrocarbon with 3 carbon atoms; C_4 is a hydrocarbon with 4 carbon atoms, C_4 includes two types of alkanes, n -butane (represented by nC_4) and isobutane (represented by iC_4).

The hydrocarbon contents (C_1 , C_2 , C_3 , iC_4 , nC_4) of the existing oil and gas layers were characterized on a map (Figure 3) to compare the hydrocarbon composition characteristics of each oil and gas layer, which providing convenience for distinguishing oil and gas reservoirs.

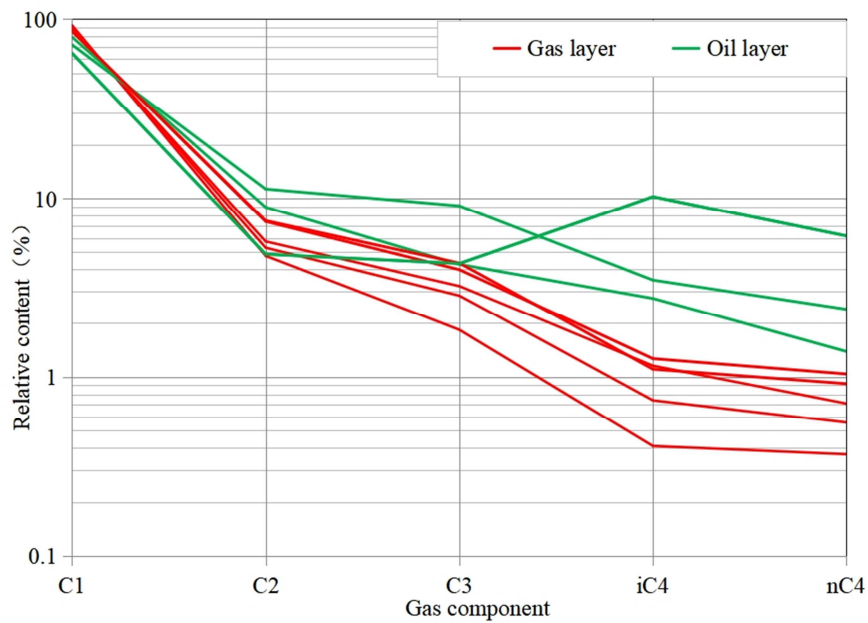


Figure 3. Distribution Characteristics of Hydrocarbon Components Obtained from Gas Logging of the X Gas Field test Layer. nC_4 is n -Butane and iC_4 is Isobutane.

3.2.2. Establishment of Critical Fluid Heavy Hydrocarbon Component Standard

The distribution characteristics of hydrocarbon components differ between oil layers that have different components and between gas layers that have different gas–oil ratios [30]. The well data of the X gas field are rich, and there are many test layers. The gas samples of each test layer were therefore analyzed using component analysis, and the distribution characteristics of the gas hydrocarbon component phases in the test layer were calculated. As shown in Figure 2, through the comparison of different hydrocarbon components in oil and gas reservoirs, it can be seen that the level of light hydrocarbon components such as C_1 and C_2 is not significantly related to fluid properties, while heavy hydrocarbon components have a good correspondence with oil and gas reservoirs. The heavy hydrocarbon components in gas reservoirs are lower, while those in oil reservoirs are higher, indicating a significant difference between the two. Collect gas logging data from confirmed oil and gas reservoirs in each testing layer, study the critical trend line (when C_3 is

3.5%, iC_4 is 1.5%, and nC_4 is 1.1%) of heavy hydrocarbon components in oil and gas reservoirs, and provide a basis for distinguishing gas and oil reservoirs.

3.2.3. Distribution Characteristics of Heavy Hydrocarbon Components in Oil and Gas Layers

The results showed that the gas layer mainly comprised C_1 – C_5 , the methane content accounted for generally more than 80%, and the heavy component content was low. The heavy hydrocarbon component was smaller than that of the critical oil and gas layer. Under normal conditions, the distribution characteristics of hydrocarbon components in condensate gas layers are also related to the gas–oil ratio. The higher the gas–oil ratio, the lower the heavy hydrocarbon composition.

The C_1 content of the oil layer is similar to that of the gas layer, but the content of heavy components is higher. Some oil layers may have extremely high light hydrocarbon content, with C_3 components below the critical line, but the heavy hydrocarbon content of iC_4 and nC_4 is still above the critical line.

4. Results and Discussion

4.1. Discriminating Between Oil and Gas Layers in the X Gas Field

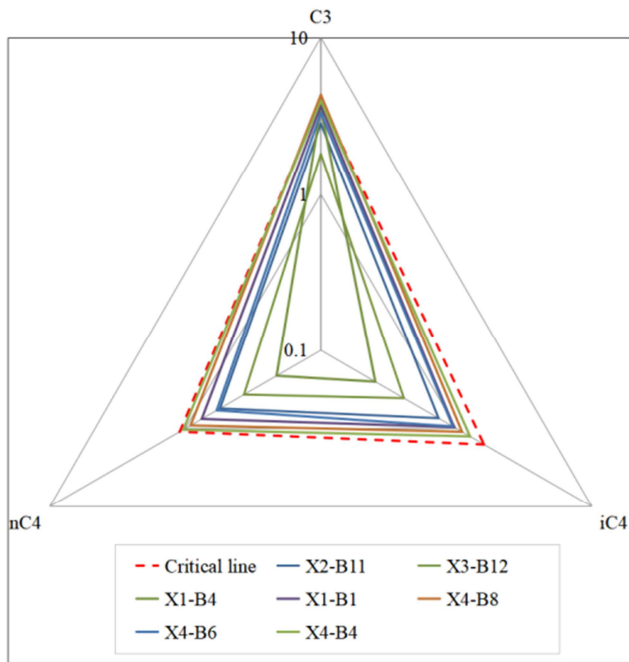


Figure 4. Distribution Characteristics of Heavy Hydrocarbon Components in Gas Reservoirs of the X Gas Field. nC_4 is n-Butane and iC_4 is Isobutane.

The oil and gas in the X gas field have obviously different distribution characteristics, and the H and P layers are mainly oil and gas layers, respectively. In order to better compare the characteristics of heavy hydrocarbon components in different oil and gas reservoirs, the author drew a triangular chart with three parameters of heavy hydrocarbon components C_3 , iC_4 , and nC_4 , and distinguished fluid properties by comparing the differences between oil and gas layers and critical layers.

The analysis of gas logging data samples from the X gas field shows that the distribution characteristics of the hydrocarbon components in the gas logging data from the oil and gas reservoirs are similar to those obtained from the test layer. However, the heavy hydrocarbon components of the gas reservoir are all lower than the critical layer, located within the triangle displayed by the critical layer (Figure 4).

For oil layers, a typical feature is the presence of higher heavy hydrocarbon components than the critical layer, as shown in Figure 5, which shows a larger triangular feature on the chart. The lower the gas-oil ratio of the oil layer, the greater the difference from the critical layer. The C_3 content of some of the layers is smaller than that of the critical layer; C_4 is the standard oil layer characteristic, and it is located outside the critical layer. As shown in Figure 5, all of the heavy hydrocarbon components in the gas logging of the A4 layer of well X6, the A7 layer of well X4, and the A6 layer of well X5 are outside of the critical oil and gas layer. In the A4 layer of well X2, the C_3 component is within the critical layer, but iC_4 and nC_4 are outside of the critical layer (represented by the large triangle). The target layers of the above four wells are

confirmed as oil layers. Comparing the heavy hydrocarbon components iC_4 and nC_4 is also an effective method for identifying oil layers.

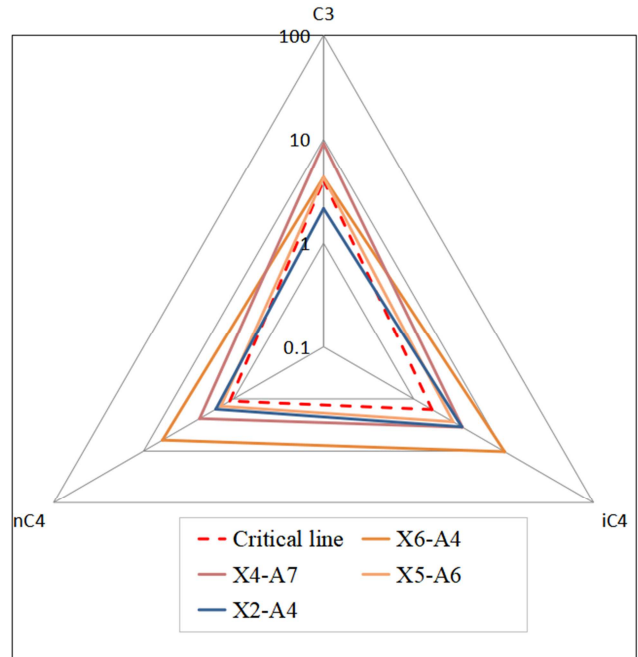


Figure 5. Distribution Characteristics of Heavy Hydrocarbon Components in the X gas Field. nC_4 is n-Butane and iC_4 is Isobutane.

4.2. Discriminating Between the Oil and Gas Layers in the Y Gas Field

The Y gas field is located within the oil and gas field production area where light oil reservoirs and condensate gas reservoirs are developed. Well Y5 is used to evaluate development in the Y gas field, and new oil and gas layers have been found in multiple layers. However, identifying fluid in the B3 layer is challenging for drilling personnel, and this layer is more developed in the region, as shown in Figure 6. Drilling and cable logging data show that the B3 layer is characterized by low gamma, high resistivity, and high gas logging at 3422–3431 m, which is representative of a typical oil and gas layer. The intersection point of neutron density in this layer is obvious and has certain gas layer characteristics. It is interpreted as a gas layer during the drilling phase and does not match the regional oil and gas distribution pattern.

Based on the gas logging data of the gas field, a distribution map of heavy hydrocarbon components in the critical layer was established and compared with the gas logging data of the B3 layer in well Y5. Gas logging samples were selected at different locations in the B3 layer for evaluation. As shown in Figure 7, the gas logging components of the two samples at depths of 3424 m (Sample point 1) and 3429m (Sample point 2) have similar characteristics, and the two almost overlap, indicating similar fluid properties. Compared to the critical layer, the sample points have higher content of nC_4 and iC_4 , located in the oil layer area of the fluid discrimination chart, and are interpreted as oil layers.

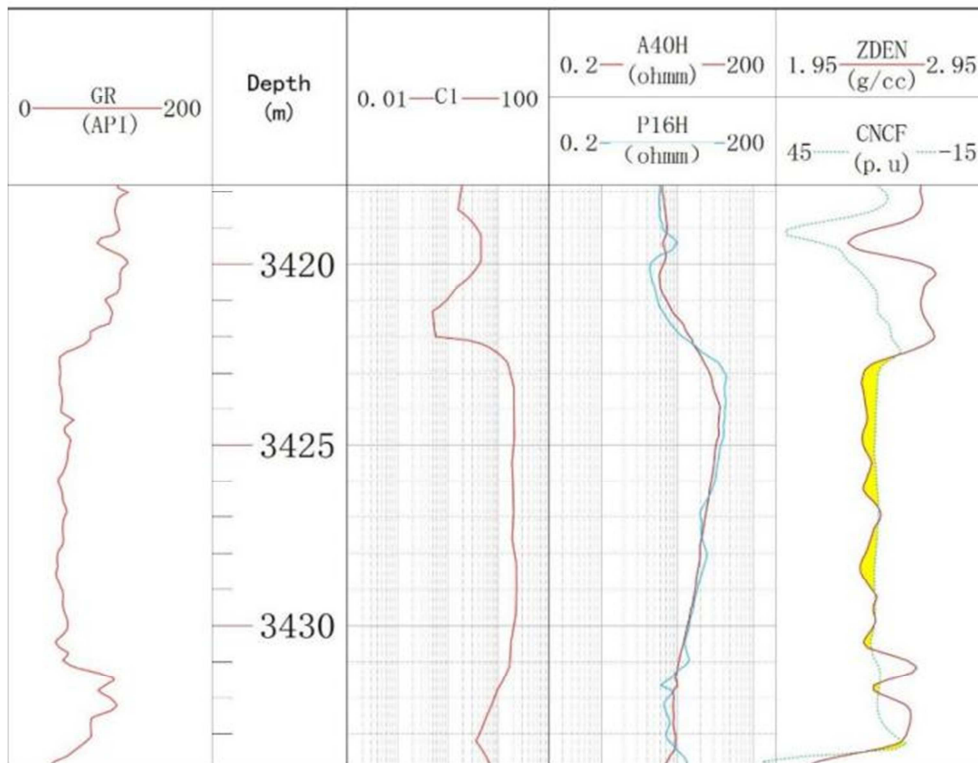


Figure 6. Logging Curve of the B3 Layer in Well Y5 of the Y Gas Field.

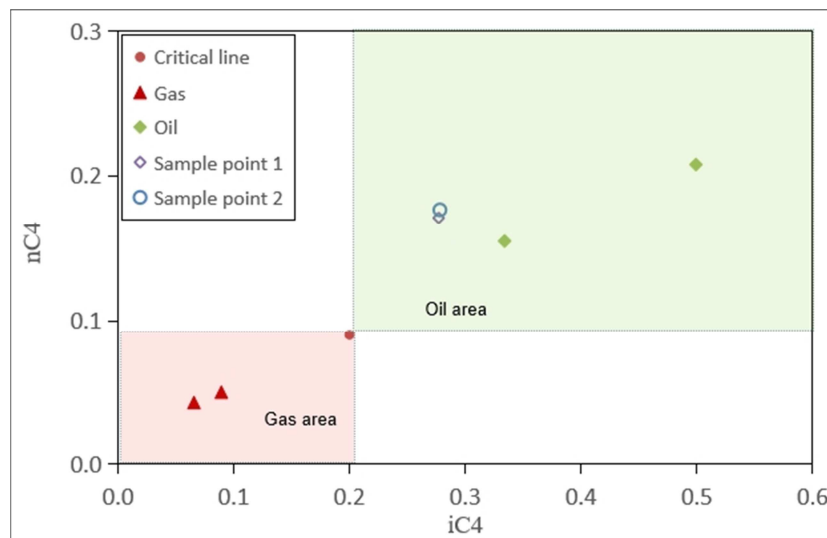


Figure 7. Oil Layer Discrimination Chart Based on Heavy Hydrocarbon Components in Y Gas Field. nC_4 is n-Butane and iC_4 is Isobutane.

Following the completion of Well Y5, the B3 layer was single-produced, and production was stable with a gas-oil ratio of $300 \text{ m}^3/\text{m}^3$, which is a typical reservoir characteristic. This result confirmed the general applicability of the hydrocarbon component distribution method in this area.

4.3. Improvement to Traditional Methods

Based on drilling data from the X gas field, the use of the traditional gas logging interpretation method to identify oil and the distribution of hydrocarbon component characteristics was compared and analyzed. As shown in Figure 8, Well X4 is

a developed well that has been put into production. Based on the heavy hydrocarbon composition method, it is determined that there are three oil layers (represented by green boxes) above 2850m, and three gas layers (represented by red boxes) below 2850 m. The results have been confirmed by testing and production data.

In order to compare the differences between different methods more intuitively, the judgment indicators of traditional methods are plotted as continuous curves, and the non matching ones are identified (represented by black boxes). From the judgment results of the Pixel hydrocarbon ratio, it

can be seen that among the three key parameters C_1/C_2 , C_1/C_3 , and C_1/C_4 , there is a discrepancy between the first two for identifying oil layers (represented by a black box). Compared with the 3H method discrimination results, the discrimination results of the feature ratio Ch are consistent with the actual

drilling situation, while the cross plot of the humidity ratio Wh and equilibrium ratio Bh has a misjudgment of the first oil layer. For the triangle chart method, there is a misjudgment in the interpretation results of the first and third oil layers on the chart.

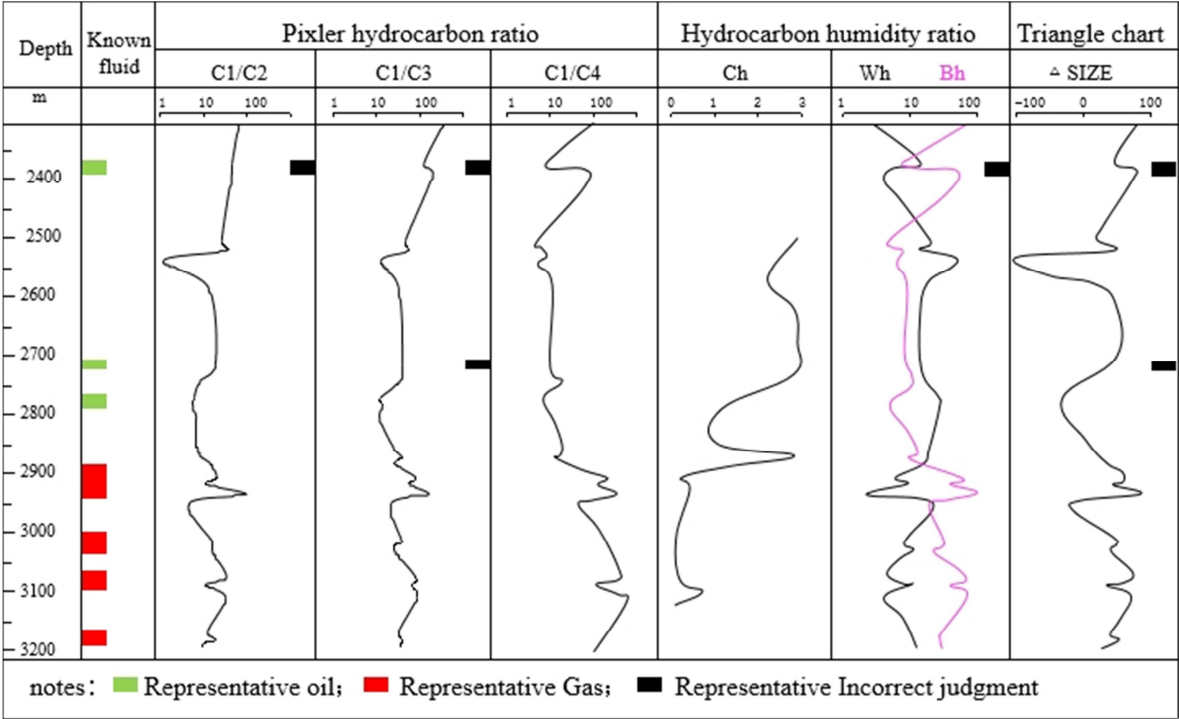


Figure 8. Effect of Conventional Gas Logging Interpretation Methods on Fluid Identification in Well X4.

According to the gas logging interpretation results of 171 oil and gas display layers in 25 wells within X and Y gas fields, the hydrocarbon component distribution characteristic method provided an interpretation coincidence of 89.5%, which was 10% higher than that of the traditional gas logging method. In summary, the combined use of the two methods greatly improved the rate of identifying oil and gas layers using gas logging data, with the aim of accurately identifying oil and gas layers.

5. Conclusion

The use of conventional gas logging interpretation methods is limited when aiming to identify light oil and condensate gas reservoirs. The heavy hydrocarbon component distribution method developed here uses data from different gas-logging components to distinguish fluid properties. Its application effect in the Xihu Sag is superior to that of previous technologies, and it thus provides a new solution for fluid property discrimination.

When developing offshore oil and gas fields, it is necessary to reduce development costs, understand the underground conditions as quickly as possible, and formulate reasonable development technology policies. In this respect, the hydrocarbon component distribution characteristics method can be applied in the study area, and it has good application prospects in mature areas.

Declarations of Interest

The authors declare that they have no competing interests.

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