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Genesis connections among different phase states of natural gas in Nanpu sag

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Abstract: To identify the genesis connection of the complex phase states of the gas in Nanpu Sag is conducive to the natural gas exploration achievements in the area. Based on the geochemical behavior of natural gas, the formation PVT and deliverability data, the phases of underground natural gas, and its distribution characteristics were studied, the origin of phases of natural gas and their relationship were analyzed; and sealing limit of different phases of gas was given from macro and micro sealing mechanism of caprock, by using faulted thickness of caprock and displacement pressure; exploration direction of natural gas was determined by the geochemical tracing method.

Key words: *genesis of natural gas; occurrence status of natural gas; phase state of natural gas; preservation condition; Nanpu sag*

I. INTRODUCTION

Nanpu sag is located in the northeast of huanghua depression in the Bohai Bay basin, and it is a meso-cenozoic composite half graben concave, that developed on the Paleozoic, Mesozoic basement. The internal of the sag was divided into two regions by the Gaoliu fault, north district is the depocencer of the Shahejie formation, developed Liuzan、Gaoshangbao drape anticline belt and Shiyang sub-concave, southern district is the depocencer of the Dongying formation, developed Laoyemiao、Beiopu reverse drag anticline belt, Nanpu No.1 to No. 5 structure, and two negative tectonic units called Linque and Liunan[1]. Layer planted from bottom to top are lower Paleozoic Cambrian-Ordovician (∈-O), Mesozoic Jurassic-Cretaceous(J-K), Paleogene(Shahejie formation Es, Dongying formation Ed) and Neogene (Guantao formation Ng, Minghuazhen formation Nm) and Quaternary (Pingyuan formation Qp), among them, Dongying Member (Ed^3)、Shayi Member(Es^1) and Shasan Member(Es^3) were the most important development layer of hydrocarbon source rocks in Nanpu sag[2].

II. THE TYPR OF NATURAL GAS PHASE STATE

First, we determined the occurrence status of natural gas in the underground. According to Dai Jinxing discriminant chart, based on correlation between the carbon isotope values of methane $\delta^{13}C_1$ and C_1/C_{2+3} to discriminate. Natural gas was divided into condensate oil associated gas and crude oil associated gas two types [3].

The second classification method was based on function fitting between dissolved gas oil ratio (GOR, Formula one) under the formation conditions and reservoir static pressure P, according to the dissolved gas oil ratio with reservoir temperature pressure, we can judge the enrichment state of natural gas in the underground. When the actual gas production rate was less than or equal to product of actual oil production and GOR, the natural gas produced was all derived from the gas which dissolved in the oil, at this time the natural gas phase state was oil-dissolved gas. While the actual gas production rate was more than product of actual oil production and GOR, it shows that not only the contribution of dissolved gas in crude oil for the output of natural gas, but

have free state of natural gas, and here the natural gas phase state was gag-cap gas.

$$GOR=G/O \quad (1)$$

In the formula, G is natural gas content in the reservoir temperature pressure, m^3; O is the amount of crude oil in the reservoir temperature pressure, m^3.

From this we can know, comprehensive consideration of the genetic types of natural gas and its coexistence with crude oil in the reservoir temperature pressure, phase state of underground natural gas can be divided into three types of in the study area, one is dissolved in the oil called oil-dissolved gas, and others are free called gas-cap gas and condensate gas. More important, crude oil associated gas corresponding to the gas cap, condensate oil associated gas corresponding to the oil- dissolved gas and condensate gas (Figure 1).

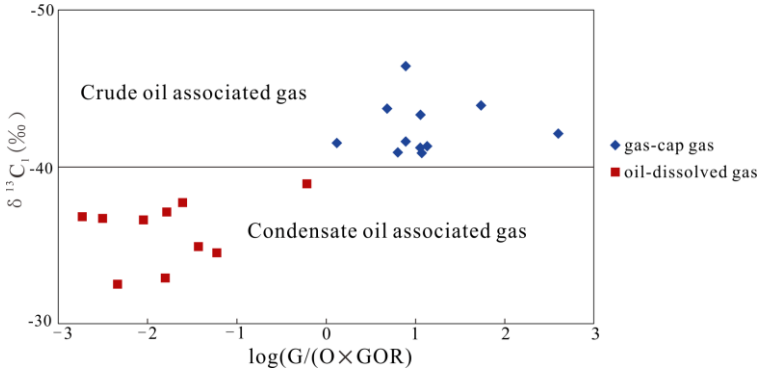

Fig.1The correlation between genetic types and reservoir types of natural gas in Nanpu sag (Another part of the gas is not producing oil in practical production, so the denominator is zero no significance, could not be marked in the picture.)

III. CONTRIBUTING FACTOR OF NATURAL GAS PHASE STATE AND RELATIONSHIP

3.1 Geochemical characteristics of each gas phase state

We studied the composition and isotopic characteristics of natural gas, draw the various parameters of natural gas into a statistical table. Research results showed that the natural gas of different phases in the Nanpu sag was dominated by hydrocarbon gas, non-hydrocarbon gases were dominated by N_2 and CO_2, and the gas had the typical characteristics of moisture (Table 1). The difference of geochemical characteristics was mainly reflected in three aspects, the content of natural gas, the drying coefficient and the carbon isotope of gas component.

(1) Component content of natural gas

Methane volume fraction of gas condensate was high, average value was 80.99%, several gas-cap gas sample had very high methane content, can reach 94.66%, and this was related to the location of the sample in the high position of structure. In non-hydrocarbon gases the sample which nitrogen volume fraction was more than 3% accounts for 33% of total gas-cap gas samples, for 50% of the total condensate gas sample and for 66% of the total oil-dissolved gas sample. This reflects the preservation condition of gas-cap gas was the best and the worst was the oil-dissolved gas. It may be explained that poor preservation conditions lead to gas cap difficult to form and the oil- dissolved gas was the main in the condition of the shallow layer oil field gas. The carbon dioxide volume fraction of condensate gas was the highest, some can reach 11%~17%.

(2) Aridity coefficient of natural gas

The aridity coefficient of the condensate gas was relatively high, this was due to a higher degree of hydrocarbon generation evolution. While the aridity coefficient of oil-dissolved gas and gas-cap gas was lower, most in the range of 0.5~0.8 and mostly moisture, owing to associated with crude oil.

(3) Carbon isotope of natural gas component

Natural gas generally has a positive carbon isotope sequence, the $\delta^{13}C_1$ of gas-cap gas was less than -40‰, and for oil-dissolved gas and condensate gas was more than -40‰, this was caused by a high degree of condensate gas and oil-dissolved gas maturity, while the gas cap gas maturity was low. The$\delta^{13}C_2$ and $\delta^{13}C_3$ of condensate gas and oil-dissolved gas was generally higher than that of gas-cap gas, part of the sample was between oil type gas and coal-type gas, and condensate gas was higher.

Table.1 The geochemical characteristic of different phase natural gas in Nanpu sag

The phase of gas	The content of gas components				The carbon isotopic composition of gas components			aridity coefficient
	C_1 (%)	C_2 (%)	N_2 (%)	CO_2 (%)	$\delta^{13}C_1$ (‰)	$\delta^{13}C_2$ (‰)	$\delta^{13}C_3$ (‰)	
gas-cap gas	57.60~94.66 (76.70,14)	0.86~21.95 (8.94,14)	0.29~7.35 (2.58,14)	0.04~9.89 (2.73,14)	-45.9~-40.9 (-43.1,14)	-34.2~-26.3 (-28.6,14)	-31.2~-24.3 (-26.8,14)	0.58~0.99 (0.81,14)
conden-sate gas	53.67~88.37 (77.10,9)	6.08~17.18 (9.00,9)	0.65~7.37 (3.5,9)	0.21~2.04 (1.8,9)	-38.9~-32.5 (-36.2,9)	-24.4~-29.0 (-27.1,9)	-22.5~-27.3 (-25.7,9)	0.58~0.96 (0.83,9)
oil-diss-olved gas	71.01~89.99 (80.99,10)	4.61~11.02 (6.08,10)	0.24~7.40 (2.39,10)	0.23~17.16 (4.46,10)	-38.5~-35.0 (-36.3,10)	-27.4~-23.8 (-25.5,10)	-26.4~-20.9 (-23.4,10)	0.78~0.92 (0.87,10)

3.2 Characteristics of natural gas genesis

According to Dai Jinxing's formula for calculating Ro of oil type gas, $\delta^{13}C_1$=15.8lgRo-42.2, we calculated the maturity value of various types of natural gas and drawn the relationship between the maturity and depth of natural gas (Figure 2). Through statistical comparison, we consider the maturity boundary between gas-top gas and pure condensate gas (and oil-dissolved gas) was Ro= 1.25%.

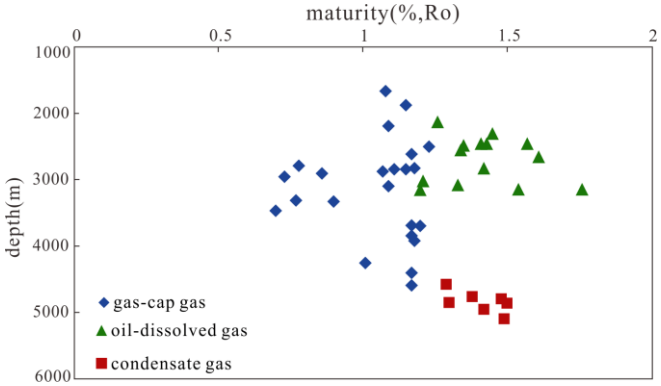

Fig.2 The correlation between maturity and depth of natural gas in Nanpu sag

Source rocks in the 3500m to enter the hydrocarbon generation threshold, Ro can reach 0.6%, because the organic matter type was mixed type, the oil generation process of oil was accompanied by the generation of natural gas, after migrated to the shallow layer, the reservoir was formed, and produced gas-cap gas due to the gravity differentiation[4]. With the increase of the thermal evolution of source rocks, source rocks enter the stage of producing natural gas, and main type was condensate gas, a partial condensate gas accumulation in the deep layer, the other part of the condensate gas was constantly migration to the shallow layer, part of the gas liquefied due to the reduction of temperature and pressure, here main type of natural gas was oil-dissolved gas [5].

IV. ANALYSIS OF SEALING CONDITIONS OF NATURAL GAS

4.1 Natural gas migration effect

During the natural gas from deep formation migrated to shallow layer, owing to the impact of

temperature、pressure、water salinity、hydrocarbon component and other factors, the dissolving power of natural gas component in oil and water would change accordingly. Research results showed that when the condensate gas stemmed from Shasan Member (Es^3) source rocks migrate upward, mainly dissolved oil gathered in the shallow layer convert into oil-dissolved gas. According to the difference between sampling depth of each well and regenerative palaeodepth used Ro value, the distance of vertical migration of natural gas was obtained. Natural gas lateral migration distance acquired by measuring the distance between sample and equivalent mature source racks in the plane. After we calculate the sum of squares of the vertical migration distance and lateral migration distance, and then extract the root obtained linear distance [6]. Overall, gas-cap gas migration distance was relatively short, mainly concentrated in the range of 3000m to 4500m (Figure 3), condensate gas migration distance was farther than gas-cap gas, mainly on the range of 3500m to 5500m, and oil-dissolved gas had the farthest migration distance, mainly on the range of 6000m to 10000m. The migration distance of natural gas could reflect evolution regulation of natural gas phase state.

4.2 Sealing mechanism and Sealing conditions of different phase states of natural gas

It is generally accepted that the fault has played a double role in the process of natural gas accumulation, it can provide a passageway for natural gas migrate from deep to shallow layer, and also as sealing condition for the accumulation of natural gas. We use faulted thickness of caprock to study the damage of the cover, the smaller the value of faulted thickness of caprock, the more easily the gas was closed [7]. And studied on the capacity of sealing gas by using displacement pressure, the greater the value of displacement pressure, the more easily the gas was closed. By means of counting the value of faulted thickness of caprock and displacement pressure, we can see that the gas-cap gas was most likely to be closed by caprock or fault, followed by condensate gas and the last was oil-dissolved gas (Figure 4). The results of actual exploration were also confirmed this point.

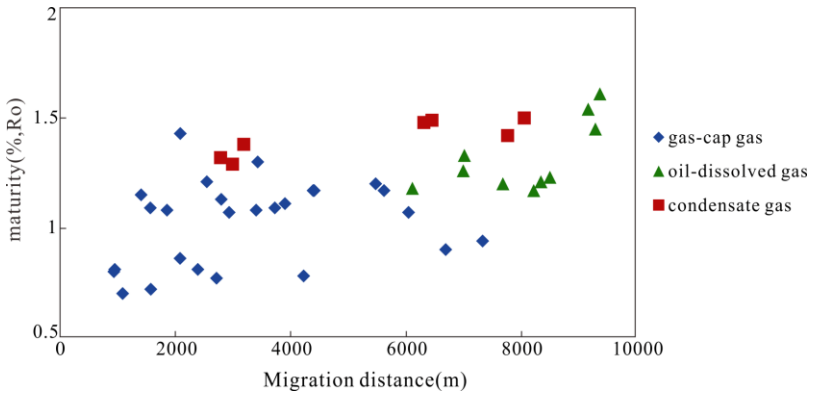

Fig.3 The contrast of migration distance of different phase natural gas in Nanpu sag

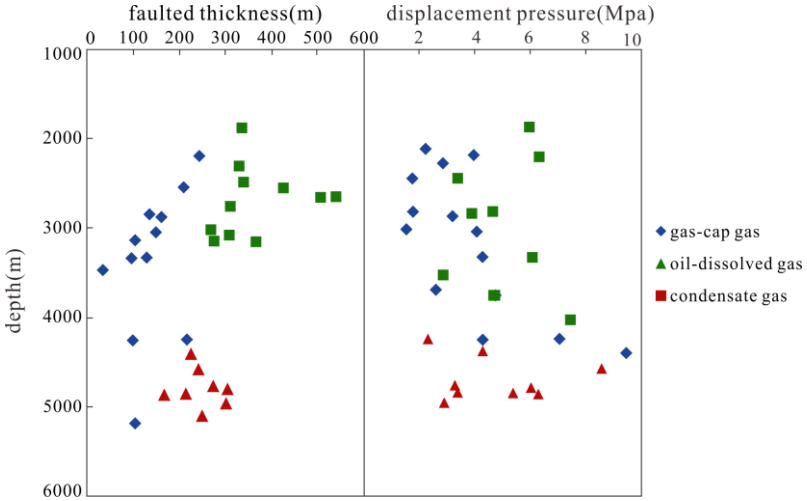

Fig.4 The thickness and displacement pressure of top cover layers of different phase natural gas in Nanpu sag

V. CONCLUSION

(1) The results show that phase states of the natural gas in Nanpu sag can be divided into three phase states: oil-dissolved gas, gas-cap gas, and condensate gas. The genetic type of gas-cap gas for crude oil associated gas, and oil-dissolved gas and condensate gas for condensate oil associated gas.

(2) The source rock of Shasan Member (Es^3) generated natural gas when enter mature oil generation stage, then the natural gas get differentiate after migrate to shallow layer and generated gas-cap gas. Then during high mature stage, natural gas was generated and part of gas accumulated in deep zone form condensate gas reservoir, others migrated to the shallow layer developed oil-dissolved gas.

(3) For three type of natural gas in Nanpu sag, the gas-cap gas was most likely to be closed by caprock or fault, followed by condensate gas and the last was oil-dissolved gas.

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