Geochemical characteristics and genesis of tight sandstone gas in Xinguang area, Junggar Basin

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Abstract. Based on the study of natural gas geochemical characteristics, combined with carbon isotope composition distribution of n-alkanes in condensate oil associated with tight sandstone natural gas, the source of natural gas in Jiamuhe Formation tight sandstone reservoir from Xinguang area of Zhongguai uplift in Junggar Basin was determined. The result shows, hydrocarbon generation potential of three sets of source rocks in Permian is: Fengcheng Formation > Lower Wuerhe Formation > Jiamuhe Formation. Lower Wuerhe Formation source rocks generate oil and gas. And C7 light hydrocarbons composition of the natural sandstone reservoir of Jiamuhe Formation in Xinguang area is dominated by n-heptane, with content more than 40%, content of methylcyclohexane is less than 40%, and carbon isotope distribution of ethane is between -29.0‰ and -27.0‰, which shows the gas origin from sapropelic source rock. The carbon isotope composition distribution of n-alkanes in condensate oil associated with the tight sandstone natural gas of Jiamuhe Formation is “valley” type, which is consistent with source rock of Lower Wuerhe Formation, indicating that the condensate oil from Xinguang area is derived from Lower Wuerhe Formation source rock. According to comprehensive analysis, the tight sandstone gas of Jiamuhe Formation in Xinguang area of Junggar Basin is mainly derived from high-mature Lower Wuerhe Formation source rock.

1. Introduction

According to the tight sandstone gas industry standard promulgated by the National Energy Administration in 2011, the sandstone gas reservoir with a median permeability of \( \leq 0.1 \times 10^{-3} \) μm² is a tight sandstone gas reservoir. The discovery of the Permian Jiamuhe Formation gas reservoir in the Xinguang area of Zhongguai uplift in Junggar Basin shows good prospects for natural gas exploration in Junggar Basin. Among them, the daily natural gas production of the single wells in XG1 well, G3 well and ZJ7 well reached \( 2 \times 10^4 \) m³, and the gas production of ZJ2 reached \( 8.9 \times 10^4 \) m³. Jiamuhe Formation reservoir in this area is generally dense, with an average porosity of 7% and an average permeability of \( 0.05 \times 10^{-3} \) μm², which is typical dense reservoir. Zhongguai uplift is adjacent to three major hydrocarbon-producing depressions: Mahu depression, Penyijingxi depression and Shawan depression. Due to rare occurrence of Permian source rocks, the understanding of hydrocarbon generation potential and characteristics of the source rocks of the Permian Jiamuhe Formation and the
Wuerhe Formation is lacking, and the understanding of natural gas sources around central depression and Shawan depression mainly based on geological inference, there is no solid geochemical basis.

Based on the light hydrocarbon and carbon isotope composition of natural gas, carbon isotope analysis of normal alkanes in natural gas-associated condensate, and evaluation of hydrocarbon generation potential of Permian source rocks, genesis of the tight sandstone gas from Jiamuhe Formation of Xinguang area in Junggar Basin is discussed.

2. Geographic location
The tight sandstone gas reservoir of Jiamuhe Formation in Xinguang area is located on south wing slope of Zhongguai uplift in northwestern margin of Junggar Basin, south of fault on the eastern side of H3 well. The area develops a north-west reverse fault and a near-east-west strike-slip fault, and develops a broad platform and a nasal structure in fault block. Jiamuhe Formation gas reservoir in Xinguang area is a fault-controlled tectonic gas reservoir. Zhongguai uplift is adjacent to three major hydrocarbon-producing depressions: Mahu depression, Penyijingxi depression and Shawan depression, which develops three sets of source rocks of Jiamuhe Formation, Fengcheng Formation and Lower Wuerhe Formation. The source rock provides sufficient hydrocarbon source for the area.

3. Results and discussion
3.1. Comparison of geochemical characteristics of natural gas from Xinguang area and Wuba area
The Wuba area of Karamay Oilfield is located in the lower part of Kebai fault zone on the northwestern margin of Junggar Basin. It is located on the north wing slope of Zhongguai uplift, north of fault on the eastern side of H3 well. The Permian Jiamuhe Formation gas reservoir was discovered in the area. And predecessors believed that natural gas in the area and in the Wuba area of the northwestern margin were from Jiamuhe Formation source rock.

By comparing the natural gas composition of Jiamuhe Formation in Xinguang area with the natural gas composition in Wuba area, it is found that the natural gas characteristics of the two regions are quite different (Figure 1). The natural gas of Wuba area is dry gas, drying coefficient exceed 0.95, carbon isotope composition of methane and ethane is heavy, and carbon isotope value of ethane is substantially greater than -26.5‰, which is a highly mature humic gas. The carbon isotope values of ethane in Jiamuhe Formation gas reservoir in Xinguang area are significantly lighter than those in Wuba area gas reservoir, distributed between -29.0‰ and -27.0‰, indicating that it is a metamorphic type of transitional gas.

![Figure 1. Carbon isotope characteristics and light hydrocarbons composition of natural gas in Jiamuhe Formation in Xinguang area and Wuba area, Junggar Basin.](image-url)
The C_7 light hydrocarbons composition of natural gas in Jiamuhe Formation gas reservoir in Xinguang area is dominated by n-heptane, and content of methylcyclohexane does not exceed 40%, reflecting that its parent material is derived from sapropelic source rock. But the C_7 light hydrocarbons composition of natural gas from the Jiamuhe Formation source rocks in Wuba area is mainly composed of methylcyclohexane and the content is over 70%, reflecting that its parent material is derived from humic source rock.

Difference in ethane carbon isotope and light hydrocarbon composition between the natural gas of Jiamuhe Formation natural gas in Xinguang area and Wuba area reflects different sources of natural gas parent materials in the two regions, indicating that natural gas in the Jiamuhe Formation gas reservoir in Xinguang area is not derived from source rocks of Jiamuhe Formation.

3.2. Hydrocarbon generation simulation experiment of Permian source rocks

In order to accurately evaluate the oil-producing potential of source rocks of Jiamuhe Formation, Fengcheng Formation and Lower Wuerhe Formation, and to identify the gas source of Jiamuhe Formation natural gas in Xinguang area, simulation experiment of hydrocarbon generation and hydrocarbon expulsion in source rock was carried out by using formation porosity thermocompression simulation experiment developed by Wuxi Research Institute of Petroleum Geology, SINOPEC. The technology adopts a sample of “retaining the original mineral composition and organic matter of source rock” and completely fills high-pressure liquid water (formation fluid) in near-pore space (hydrocarbon generation space) while considering static rock pressure close to geological conditions. And high temperature short-time pyrolysis reaction of organic matter under the condition of formation fluid pressure is close to actual geological evolution process.

Table 1. Thermal simulation sample information of Permian source rocks in northwestern margin of Junggar Basin.

| Well | Formation | Lithology       | TOC/% | HI/(mg/g) | Tmax/°C |
|------|-----------|-----------------|-------|-----------|---------|
| G16  | P_1j      | Tuffaceous Mudstone | 2.76  | 71        | 433     |
| W351 | P_1f      | Tuff            | 2.37  | 608       | 436     |
| JT1  | P_2w      | Mudstone        | 2.36  | 394       | 450     |

This experimental temperature ranged from 250 °C to 500 °C, and the simulated hydrocarbon generation of source rocks was analyzed at intervals of 50 °C. The experiments were carried out using higher organic matter of Jiamuhe Formation, Fengcheng Formation and Lower Wuerhe Formation. Sample information is shown in Table 1 and experimental results are shown in Fig 2.

The source rocks of Jiamuhe Formation reached peak of oil production at 400 °C, with a peak value of 88.80 kg/t TOC, oil production rate reached maximum at 375 °C, and the oil production was 54.88 kg/t TOC; total gas production increase with the increase of experimental temperature, and the total gas production reached 66.02 kg/t TOC at 500 °C.

The source rock of Fengcheng Formation reached peak of oil production at 350 °C, with a peak value of 563.37 kg/t TOC. At this time, it is also the peak of oil production rate, with peak value of 539.59 kg/t TOC, and the total gas production reached 351.20 kg/t TOC at 450 °C.

The source rocks of Lower Wuerhe Formation reached peak of oil production at 450 °C, with a peak value of 563.37 kg/t TOC. At this time, it is also the peak of oil production rate, with peak value of 539.59 kg/t TOC, and the total gas production reached 351.20 kg/t TOC at 450 °C.

The source rocks of Lower Wuerhe Formation reached peak of oil production at 450 °C, with a peak value of 371.26 kg/t TOC, oil production rate reached maximum at 375 °C, and the oil production was 280.51 kg/t TOC; total gas production increased with the increase of experimental temperature, and total gas production reached 293.35 kg/t TOC at 500 °C.

It can be seen from the experimental results that source rocks of Lower Wuerhe Formation can produce a large amount of oil or a large amount of gas. The total amount of gas and oil production are significantly higher than that of Jiamuhe Formation source rocks. The source rocks of Jiamuhe Formation are mainly generate gas. Although source rock of Fengcheng Formation has the largest
hydrocarbon generation potential, it is mainly generate oil in the early stage, generate less gas in the late stage.

**Figure 2.** Hydrocarbon generation curve of source rocks simulation of Jiamuhe Formation, Fengcheng Formation and Lower Wuerhe Formation in Junggar Basin.

### 3.3. Carbon isotope distribution of n-alkanes in condensate from Jiamuhe Formation gas reservoir

In this paper, 7 samples of Permian source rocks were selected, including 5 samples of source rocks of Fengcheng Formation, 1 sample of Lower Wuerhe source rock and 1 sample of Jiamuhe source rock. The selected source rock samples have relatively high TOC(Table 2). By comparing the carbon isotope composition characteristics of n-alkanes in different source rocks, it is found that the carbon isotope distribution curves of normal alkanes in the three sets of source rocks of Permian are obviously different(Fig 3).

**Table 2.** Geochemical characteristics of Permian source rocks in northwestern margin of Junggar Basin.

| Source rock | Formation | Lithology      | TOC(%) | HI(mg/g) | Tmax(°C) |
|-------------|-----------|----------------|--------|----------|----------|
| JT1         | P1w       | Mudstone       | 3.37   | 550      | 450      |
| FN1-1       | P1f       | Dolomitic Mudstone | 1.82 | 505       | 440      |
| FN1-2       | P1f       | Dolomitic Mudstone | 1.22 | 447       | 437      |
| FN4         | P1f       | Mudstone       | 1.95   | 505       | 447      |
| X76-1       | P1f       | Mudstone       | 2.77   | 523       | 438      |
| X76-2       | P1f       | Mudstone       | 1.92   | 524       | 440      |
| C201        | P1j       | Tuff           | 1.64   | 55        | 453      |

The carbon isotope composition of n-alkanes in source rock of Lower Wuerhe Formation is generally light, ranging from -37.0‰ to -32.0‰, and its carbon isotope distribution curve of n-alkanes is "valley" type, with light in the middle and heavy on both sides. In the range of \( nC_{24} - nC_{26} \), the n-alkane carbon isotope is the lightest, as low as -36.97‰.

The carbon isotope composition of n-alkanes in source rocks of Fengcheng Formation is heavier than Wuerhe Formation, ranging from -32.5‰ and -29.5‰, and its carbon isotope distribution curve
of n-alkanes is "horizontal line" type, that is, the carbon isotope has no obvious change with the increase of carbon number.

The carbon isotope composition of n-alkanes in source rocks of Jiamuhe Formation is the heaviest, greater than -29.0‰, and its carbon isotope distribution curve of n-alkanes is “upward” type, with the carbon number of normal paraffins increases, the carbon isotope values gradually become heavier.

The carbon isotope composition distribution of n-alkanes in condensate oil associated with the tight sandstone natural gas of Jiamuhe Formation from XG1 well and ZJ 2 well in Xinguang area is shown in Fig. 8. It can be seen from the figure that the carbon isotope composition distribution of n-alkanes in the two wells is “valley” type, which is consistent with the source rock of Lower Wuerhe Formation. With the increase of carbon number, the carbon isotope of n-alkanes in condensate oil is gradually lightened, in the range of nC24~nC26, carbon isotope of n-alkane is the lightest, reaching -32.53‰, and then the carbon isotope gradually changes with the increase of carbon number. The carbon isotope composition distribution of n-alkanes indicates that the condensate oil associated with the tight sandstone natural gas of Jiamuhe Formation in Xinguang area is mainly derived from source rock of Lower Wuerhe Formation.

**Figure 3.** Carbon isotope distribution of n-alkanes in condensate oil and source rocks of Jiamuhe Formation, Fengcheng Formation, Lower Wuerhe Formation in Junggar Basin.

4. Conclusions
(1) Through hydrocarbon generation potential evaluation and hydrocarbon generation simulation experiments of source rocks, it is clear that Lower Wuerhe Formation source rocks is an important source of oil and gas in the northwestern margin of Junggar Basin, and its hydrocarbon generation potential is larger than that of Jiamuhe Formation source rock.
(2) Based on geochemical characteristics of natural gas, combined with carbon isotope composition distribution of n-alkanes in condensate oil associated with the tight sandstone natural gas, it is determined that the natural gas and condensate oil in Jiamuhe Formation gas reservoir in Xinguang area are mainly derived from source rock of Lower Wuerhe Formation source rock.

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