Study on characteristics and source of tight gas in the Shahezi formation, Xujiaweizi Fault Depression, Songliao Basin, China

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Abstract. The Xujiaweizi fault depression is rich in natural gas resources in Lower Cretaceous and a major fault depression of the deep strata in northern Songliao Basin. In this study, the tight gas is coaliferous gas in the K1sh Formation of the Xujiaweizi Fault Depression. The methane carbon isotope value of tight gas is controlled by mature evolution. The cause of reversed sequence and partially reversed sequence of gas components carbon isotope is carbon isotope fractionation with hydrocarbon generation evolution of high-overmature stage source rock. The carbon isotope values of the low content components are obviously lighter with the increase of buried depth at the late stage of mature evolution. The carbon isotope values of adsorbed gas show similar characteristics, whether mudstone, carbonate or coal in the same well. The tight gas reservoir is self-generation and self-accumulation gas reservoir by vertical diffusion and short distance migration in the K1sh Formation of the Xujiaweizi Fault Depression. It is important to study on the geochemical characteristics and the genesis of tight gas for guiding the exploration and deployment in the future.

1. Introduction

The Xujiaweizi Fault Depression lies in the Songliao Basin of northeast China ‘Figure 1’. It is rich in natural gas resources in Lower Cretaceous and a major fault depression of the deep strata in northern Songliao Basin. The Xujiaweizi Fault Depression is extended in north-south direction with an area of about 3300 Km². In 2001, Well XS1 obtained high-yield industrial gas flow in volcanic reservoirs of Yingcheng Formation (K1yc) in the Xujiaweizi Fault Depression, which opened the prelude to the exploration and development of deep natural gas of Lower Cretaceous in Songliao Basin. With the increasing importance of unconventional oil and gas, the proportion of unconventional oil and gas is increasing in the new reserves and production. In recent years, the Xujiaweizi Fault Depression exploration by the volcanic reservoir extended to tight sandy conglomerate reservoir. It is important to study on the geochemical characteristics and the genesis of tight gas for guiding the exploration and deployment.

The deep strata refer to the layers below the second member of Quantou Formation in the Songliao Basin. From bottom to top, they are Huoshiling Formation of Upper Jurassic (J1HSL), Shahezi Formation of Lower Cretaceous (K1sh), Yingcheng Formation (K1yc), Denglouku Formation (K1d), the first and the second members of Quantou Formation (K1q1+2). The main gas source rocks of the deep strata are
dark mudstone, carbagilite and coal, including J\(_{\text{HSL}}\) Formation, \(K_{\text{1sh}}\) Formation, the fourth member of \(K_{\text{1yc}}\) Formation, and \(K_{\text{1d}}\) Formation. Among them, the \(K_{\text{1sh}}\) Formation is the main exploration target as well as the main gas source rock formation for tight gas in the Xujiaweizi Fault Depression at present. Tight gas reservoirs have been discovered, and many tight gas wells have obtained industrial gas flow in the \(K_{\text{1sh}}\) Formation.

![Figure 1](image.png)

Figure 1. Map shows the location of the study area: Xujiaweizi Fault Depression

2. **Samples and experiments**

2.1. **Samples**

The samples of this study include 60 natural gas samples from 22 wells, 43 core samples from 28 wells which 37 core samples are dark mudstone and 6 core samples are coal. They are all from the \(K_{\text{1sh}}\) Formation of the Xujiaweizi Fault Depression.

2.2. **Experiments**

All natural gas samples are analyzed for gas composition and carbon isotope. Each core sample is divided into two parts.

One part is used for chloroform extraction analysis. The core samples were cleaned using redistilled water. The samples were subsequently dried at 60\(^\circ\)C and ground to powder. The powder samples were analyzed (using Rock–Eval 6) for total organic carbon (TOC), hydrogen index (HI), and hydrocarbon generation potential (S1+S2). The powdered samples were extracted using a Soxhlet apparatus. All extracts were separated into saturates, aromatics, resins and asphaltenes fractions using column chromatography. Stable carbon isotope analysis was performed on the group fractions of source rock samples.

The other part is analyzed by acidolysis hydrocarbon, which is considered as adsorption gas of gas source rock. Adsorption gas samples are also analyzed for gas composition and carbon isotope, and compared with natural gas samples in wells.

3. **Results and discussion**
3.1. Natural gas characteristics

The methane carbon isotope of tight gas are -33.24 ~ -25.51‰ in the K1sh Formation of the Xujiaweizi Fault Depression. Derived from type III kerogen, it belongs to coaliferous gas, and is similar to the natural gas genetic type in the K1yc Formation of volcanic gas reservoir in the Xujiaweizi Fault Depression. However, it is obvious differences in the carbon isotope value of tight gas components among wells. For example, the carbon isotope values of tight gas components are in the positive sequence of Well DS3-1 in the K1sh Formation of Anda area, northern Xujiaweizi Fault Depression ‘Figure 2 (a)’, whereas the carbon isotope values are in the reverse sequence of Well ZS12 of Zhaozhou area, southern Xujiaweizi Fault Depression ‘Figure 2 (b)’. Meanwhile, the carbon isotope distributions of tight gas of the same well in K1sh and K1yc are similar, reflecting the same source of natural gas reservoirs.

![Figure 2. Natural gas plots of Well DS3-1 (a) and Well ZS12 (b) in the Xujiaweizi Fault Depression, Songliao Basin, China](image)

Study on the carbon isotope values of tight gas components of the K1sh Formation reveals that carbon isotope values of methane, ethane, propane and butane change obviously from a positive sequence (Anda area ‘Figure 3 (a)’ and Songzhan area ‘Figure 3 (b)’ in the northern Xujiaweizi Fault Depression) to a partially reversed sequence (XuxiXudong area ‘Figure 3 (c)’ in the central Xujiaweizi Fault Depression), and then to a completely reversed sequence (Zhaozhou area ‘Figure 3 (d)’ in the southern the Xujiaweizi Fault Depression). The main frequency of methane carbon isotope of these natural gas is all -30~ -25‰. The main differences are the carbon isotope values of ethane, propane, and butane that are getting lighter and lighter from Anda area, Songzhan area, XuxiXudong area to Zhaozhou area. By comparing the distribution of gas source rock maturity, it is found that the gas source rock maturity (Ro) of the northern Xujiaweizi Fault Depression is 2-3%, while the gas source rock maturity (Ro) of in the southern Xujiaweizi Fault Depression is more than 3%. The cause of reversed sequence and partially reversed sequence of gas components carbon isotope values is carbon isotope fractionation with hydrocarbon generation evolution of high-overmature stage source rock.

The carbon isotope values of the aromatics tend to become much lighter with the increase of buried depth in source rocks of the K1sh Formation ‘Figure 4 (b)’. The carbon isotope value of the resins and asphaltenes also tend to become much lighter with the increase of buried depth ‘Figure 4 (c) and Figure 4 (d)’. But the carbon isotope of saturates does not change significantly with buried depth, mainly is -30~ -26‰ ‘Figure 4 (a)’. This indicates that the hydrocarbon is generated gradually decreases by the source rock at the high-overmature stage while fractional distillation of carbon isotope gets obvious at the late stage of mature evolution. The carbon isotope values of the low content components are obviously lighter with the increase of buried depth at the late stage of mature evolution, whether it's a gas or whether it's a liquid, such as ethane, propane, butane in natural gas, and aromatics, resins and asphaltenes in source rock extracts, the carbon isotope values can no longer fully express the kerogen type and mature evolution.
Figure 3. Natural gas plots of the K1sh Formation from the Xujiaweizi Fault Depression

Figure 4. Carbon isotope of saturates(a), aromatics(b), resins(c) and asphaltenes(d) at various burial depths from source rocks of the K1sh Formation in the Xujiaweizi Fault Depression
3.2. **Tight gas source**

Adsorbed gas samples from mudstone, carbargilite and coal are obtained by acidolysis for gas sources comparing. Taking Well SS4 for example ‘Figure 5’, the carbon isotope values of adsorbed gas of different lithologies in the K\textsubscript{1}sh Formation show similar, and are similar with the carbon isotope value of the tight gas in the same well. Indicated that the tight gas comes from local gas source rock in the K\textsubscript{1}sh Formation. The tight gas reservoir is a self-generation and self-accumulation gas reservoir in K\textsubscript{1}sh Formation of the Xujiaweizi Fault Depression.

![Figure 5. Natural gas plots of Well SS4](image)

The methane carbon isotope values of tight gas have a trend of getting heavier with the increase of burial depth in the K\textsubscript{1}sh Formation of the Xujiaweizi fault depression. The methane carbon isotope values of the adsorbed gas also have similar distribution characteristics ‘Figure 6’. Indicated that the methane carbon isotope values of tight gas are obviously controlled by the thermal evolution extent. The tight gas is in keeping with source control theory by vertical diffusion and short distance migration in the K1sh Formation of the Xujiaweizi Fault Depression.

![Figure 6. Methane carbon isotope of tight gas and adsorbed gas at various burial depths in the K\textsubscript{1}sh Formation of the Xujiaweizi Fault Depression](image)
4. Conclusions
In this study, the tight gas is coaliferous gas in the K1sh Formation of the Xujiaweizi Fault Depression. The cause of reversed sequence and partially reversed sequence of gas components carbon isotope is carbon isotope fractionation with hydrocarbon generation evolution of high-overmature stage source rock. The carbon isotope values of the low content components are obviously lighter with the increase of buried depth at the late stage of mature evolution, whether it's a gas or whether it's a liquid. The carbon isotope values of adsorbed gas of different lithologies in the K1sh Formation show similar, and are similar with the carbon isotope value of the tight gas in the same well. The methane carbon isotope value of tight gas is controlled by mature evolution. The tight gas reservoir is self-generation and self-accumulation gas reservoir by vertical diffusion and short distance migration in the K1sh Formation of the Xujiaweizi Fault Depression.

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