Study on the characteristics of in-situ gas desorption from the Wufeng - Longmaxi shale in the Sichuan Basin

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Abstract. Upper Ordovician Wufeng Formation-Lower Silurian Longmaxi Formation shale in the Sichuan Basin and its periphery is an important horizon for shale gas exploration and development in my country. The rapid on-site desorption instrument independently developed by Sinopec Wuxi Institute of Petroleum Geology was used to test the desorption gas volume, lost gas volume, total gas content, natural gas components of desorbed gas and carbon isotope of methane in typical shale gas wells in this area. Data analysis shows that the carbon isotope value and characteristics of the first sample of methane can predict shale gas enrichment layers, and the total gas content and desorbed natural gas components can identify shale gas sweet spots; shale gas components and carbon isotope values can jointly identify shale gas Genesis type, kerogen carbon isotope characteristics and shale gas carbon isotope characteristics can be used as effective means for gas source comparison; shale gas composition characteristics can distinguish the preservation conditions of the area, which are indicative for the study of the degree of shale gas loss; The combined application of total gas content and initial dissipation index can better identify the sweet spots of shale gas, and avoid single-factor identification of sweet spots; the carbon isotope value of methane shows obvious fractionation effect with desorption time, which can predict shale gas production stage and residual gas content.

1. Introduction
Shale gas refers to natural gas that mainly occurs in organic-rich shale formations in an adsorbed or free state. It has the characteristics of self-generation and self-storage, no obvious gas-water interface, and continuous distribution and enrichment in a large area in space. The organic-rich shale exploration results of the Upper Ordovician Wufeng Formation-Lower Silurian Longmaxi Formation in the Sichuan Basin and its surroundings are the most prominent. Important discoveries have been made in Jiaoshiba, Pengshui, Dingshan, Nanchuan, Weiyuan and other areas. The Sichuan Basin and its periphery are hotspots for shale gas research in China. Previous studies have shown that the total gas content test and the study of desorbed natural gas components are used to identify shale gas sweet spots, which is the most direct method for quantitative identification of shale gas sweet spots. In
addition, the characteristics of shale gas composition and carbon isotope characteristics. It is important and meaningful in the identification of shale gas genetic categories, research on accumulation mechanism and identification of enrichment regions. This paper is based on the rapid on-site desorption instrument independently developed by Sinopec Wuxi Institute of Petroleum Geology. Based on the on-site desorption of typical shale gas in the Sichuan Basin and its surroundings, the loss of gas, desorbed gas, shale gas components, The carbon isotope value and other parameters of the desorption process are tested and studied, so as to explore the significance of on-site desorption gas characteristics in the accumulation mechanism, shale gas exploration and development.

2. Regional geological features
The Upper Ordovician Wufeng Formation-Lower Silurian Longmaxi Formation in the Sichuan Basin and its periphery mainly develops in the non-compensatory anoxic environment in the relatively deep water north of the Niushoushan-Middle Guizhou paleo-uplift to the Jiangnan-Xuefeng uplift. The Upper Ordovician Wufeng Formation has a small thickness, generally no more than 30m, but its distribution is stable, covering almost the entire study area. The lithology is black siliceous shale, sandy shale, carbonaceous shale, and carbonaceous argillaceous shale. The black shale of the Lower Silurian Longmaxi Formation is concentrated at the bottom of this set of strata. It is mainly black siliceous rock, shale, carbonaceous shale, dark gray mudstone, etc. The thickness is generally about 30-120m. The distribution is similar to the Upper Ordovician black shale, which is mainly distributed in southern Sichuan, western Hubei-eastern Chongqing and northeastern Sichuan (Figure 1).

The shale of the Wufeng-Longmaxi Formation in the Sichuan Basin and its surroundings has high organic carbon content, which provides a good material basis for the formation of favorable shale gas reservoirs. Taking Well Jiaoye 1 in Jiaoshiba area, Fuling as an example, from the upper section of the Lower Silurian Longmaxi Formation to the Upper Ordovician Wufeng Formation, the lithology is mainly from argillaceous siltstone and silty mudstone to black carbonaceous shale. Excessively, the TOC value shows an increasing trend, and the organic carbon content is greater than 2.0% and the thickness of the shale is about 38m. The microscopic analysis of kerogen in the upper section of the Silurian Longmaxi Formation in Well Jiaoye 1 shows that the organic matter is mainly composed of algae and cotton-like saprophyte amorphous body, which is type I kerogen; Wufeng-Longmaxi Formation in Well Jiaoye 1 Shale has entered an over-mature evolution stage, and its maturity Ro is between 2.20-3.06 (Figure1).

![Figure 1. Study area location and typical section](image)

3. Experimental test methods and sampling
The gas content test of shale gas core wells in the Sichuan Basin and its surrounding areas is based on the drainage gas collection method, and the measurement data is not affected by water vapor and multi-component gases, which can achieve reliable volume measurement. In the desorption process, first-order desorption. The temperature adopts the mud circulation temperature, and the second-stage
temperature adopts 110°C. The instrument records a desorption data every 30 seconds, and about 1440 data will be recorded during the desorption process of about 12 hours, so as to realize a complete characterization of the desorption process. The samples were collected from the natural gas desorbed from the Wufeng-Longmaxi Formation shale gas well in the Sichuan Basin and its surrounding shale gas wells. After the core was raised to the wellhead, the rock sample was quickly placed in the desorption tank and sealed, and then placed in the desorption instrument for desorption. The saturated brine method is used for collection, and a bottle of desorbed gas is collected every 30 minutes to test its composition and alkane carbon isotope characteristics. The purpose is to record the dynamic changes of the gas composition and alkane carbon isotope value during the desorption process of shale gas (Figure 2).

![Figure 2. Onsite Gas test principle diagram](image)

4. Experimental data analysis

4.1. Identification of shale gas enriched intervals and "sweet" layers

The gas content of shale reservoirs reflects the enrichment of shale gas, and is also an important parameter that determines whether shale gas has economic value. The higher the gas content, the higher the shale gas enrichment degree, and the lower the gas content, the lower the shale gas enrichment degree. In my country, some wells have high gas content but low hydrocarbon composition. At this time, it is necessary to combine total gas content and natural gas composition to identify sweet spots. For the Jiaoshiba area, the hydrocarbon gas content in natural gas components is higher, about 98% or more, and the non-hydrocarbon gas content is relatively small. Therefore, the sweet spot can be identified by the total gas content.

Generally, when the gas content is less than or equal to 1.00 m³/t, it is a non-commercial reservoir and generally has no production value; 1.00 m³/t<gas content<2.00 m³/t is a poor gas-bearing layer, which can be commercially exploited under special conditions; 2.00 m³/t<gas content<4.00 m³/t is a medium gas-bearing zone, which is the main gas content range for current shale gas production; gas content≥4.00 m³/t is a high-quality gas-bearing zone, which can reach the core zone in Jiaoshiba area. This gas content. In the field test and evaluation of the gas content of the shale in the first section of Wufeng-Longmaxi Formation in Well Jiaoye 1, the well depth is between 2326m and 2338m, and the average gas content is 1.66 m³/t, which is a poor gas-bearing zone. The well depth is between 2338m and 2353m. Between 2353m and 2378m, the average gas content is 2.52 m³/t and 2.91 m³/t, respectively. It is a medium gas-bearing zone. The well depth is between 2378m–2411m and 2411m–2415.5m, and the average gas content is 4.73 m³/t respectively. And 6.67 m³/t, it is a high-quality gas-bearing interval, and it is also the core interval currently mined in the Jiaoshiba area (Table 1).
Table 1. The gas content and assessment of Wufeng-Longmaxi Shale of JY1

| Stratum         | Depth (m) | Min (m³/t) | Max (m³/t) | Average (m³/t) | Thickness (m) | Evaluation of gas content |
|-----------------|-----------|------------|------------|----------------|---------------|---------------------------|
| Longmaxi Formation | 2326~2338 | 1.47       | 1.83       | 1.66           | 12            | bad                       |
|                 | 2338~2353 | 2.87       | 3.08       | 2.52           | 15            | medium                    |
|                 | 2353~2378 | 2.20       | 4.03       | 2.91           | 25            | medium                    |
|                 | 2378~2411 | 2.66       | 6.60       | 4.73           | 33            | high quality              |
| Wufeng Formation | 2411~2415.5 | 6.16       | 7.18       | 6.67           | 4.5           | high quality              |

4.2. The shale gas composition and stable isotope characteristics are used to compare the gas source and identify the genetic type of shale gas

4.2.1. Natural gas source

The carbon isotope composition of alkanes is the most important indicator for identifying the genetic type of natural gas, studying oil and gas migration and oil and gas source correlation. The δ¹³C value of Lower Cambrian source rock kerogen in the Sichuan Basin and its surrounding areas is generally between -31.5‰ and -35‰, which is lower than the δ¹³C1 value of natural gas in the Longmaxi Formation. According to the gas source rock carbon isotope variation, it is high Mature natural gas should come from source rocks with slightly heavier carbon isotopes. In addition, the Wufeng-Longmaxi deep-water shelf black gas shale in the southeastern Sichuan Basin is in integrated contact with the upper Ordovician Linxiang Formation nodular limestone. The lithology is dense, and the electrical characteristics also show high-gamma, high-resistance compactness, and the bottom plate has excellent storage conditions. It shows that the Lower Cambrian source rock is unlikely to be the natural gas source rock of the Longmaxi Formation (Table 2).

Table 2. Natural gas carbon isotope of Wufeng-Longmaxi Shale in Southeast Sichuan

| Serial number | Well name | Stratum         | depth (m) | Carbon isotope value (PDB,‰, ±0.5‰) | δ¹³C₁ | δ¹³C₂ | δ¹³C₃ |
|---------------|-----------|-----------------|-----------|-------------------------------------|-------|-------|-------|
| 1             | Pengye1   | Wufeng-Longmaxi  | Wellhead gas | -29.7, -33.2                      | /     |       |       |
| 2             | Pengye1   | Wufeng-Longmaxi  | Wellhead gas | -29.3, -33.1                      | /     |       |       |
| 3             | Pengye3   | Wufeng-Longmaxi  | Wellhead gas | -29.3, -32.7                      | /     |       |       |
| 4             | Pengye3   | Wufeng-Longmaxi  | Wellhead gas | -29.3, -33.0                      | /     |       |       |
| 5             | JiaoyeX   | Longmaxi        | Initial desorption gas | -30.9, -35.5                  | /     |       |       |
| 6             | JiaoyeY   | Longmaxi        | Initial desorption gas | -30.4, -35.9                  | /     |       |       |

The δ¹³C value of kerogen in the source rock of the Longmaxi Formation in Jiaoshiba is between -29.8‰ and -29.1‰, which is slightly higher than the δ¹³C1 value of natural gas in the Wufeng-Longmaxi Formation reservoir, implying that the natural gas of the Longmaxi Formation comes from Longmaxi hydrocarbons. The possibility of source rock. The Wufeng-Longmaxi deep-water shelf facies black gas shale roof in southeastern Sichuan is a thick layer of tight shallow water facies argillaceous rock with a thickness of up to 300~400m, with good sealing conditions. The gas source rock is derived from the upper strata. The possibility is unlikely. Therefore, it is inferred that the natural gas in the Wufeng-Longmaxi Formation in the Jiaoshiba area comes from its own stratigraphic source rock, which has the characteristics of integrated source and storage. The natural gas has only undergone in-situ retention and first-time retention in the shale. Migration or short-distance secondary migration, changes in the carbon isotope of natural gas methane desorbed in different intervals suggest...
that this primary migration or short-distance secondary migration is caused by methane carbon isotope fractionation.

4.2.2. Identification of genetic type of natural gas
The natural gas components of the first section of Wufeng-Longmaxi Formation in the Sichuan Basin and its surrounding areas show the characteristics of high methane content, high drying coefficient, and no H2S. The δ13C1 of natural gas is between -30.9‰ and -29.3‰, which is in the range of oil-type gas. Inside the Sichuan Basin and its surrounding areas, the Wufeng-Longmaxi Formation shale gas negative carbon isotope sequence is widespread. The Wufeng-Longmaxi Formation shale gas in Jiaoshiba has a δ13C1> δ13C2>δ13C3 carbon isotope completely reversed phenomenon. There are carbon-negative carbon isotope sequences of methane and ethane in Pengye 1 and Pengye 3 wells in the water area. According to Dai Jinxing’s research, the inversion of the carbon isotope of Wufeng-Longmaxi Formation shale gas in southeastern Sichuan to a secondary negative carbon isotope series is caused by the high temperature experienced during the evolution of the Wufeng-Longmaxi Shale. Oil cracked gas and cheese may exist. The mixing of root cracked gas, that is, the mixing of natural gas of the same origin and different stages, and the appearance of large-scale secondary negative carbon isotope series, is a sign that the evolution of petroleum gas has entered the mature stage. Therefore, it is believed that one of the main sources of natural gas in Wufeng-Longmaxi Formation is crude oil cracked gas at a higher thermal evolution stage.

4.3. Discrimination preservation conditions of shale gas component characteristics
The Sichuan Basin and its peripheries have undergone the superimposition and transformation of multiple tectonic movements, resulting in strong fold deformation, uplift and denudation of the strata, and complicated oil and gas preservation conditions. Preservation conditions are one of the main controlling factors for shale gas enrichment and high production. Factors such as roof and floor conditions, tectonic effects, pressure coefficient, and the distance from large faults can all reflect the preservation conditions of shale gas. In addition, the characteristics of shale gas components can also identify the preservation conditions of shale gas. Natural gas with a high proportion of methane, indicating that the gas reservoir is not affected by atmospheric underwater seepage, and the storage conditions are good (Table 3).

### Table 3. Gas composition and pressure coefficient of shale gas well in Southeast Sichuan

| Region location | Well | Stratum | Pressure coefficient | Methane | Ethane | Propane | Butane | Helium | Nitrogen | Carbon dioxide |
|-----------------|------|---------|----------------------|---------|--------|---------|--------|--------|----------|---------------|
| Basin           | JY 1 | O3w-S1 | 1.45                 | 98.26   | 0.68   | 0.02    | 0      | 0.04   | 0.82     | 0.18          |
|                 |      |         | 1.45                 | 98.1    | 0.59   | 0.23    | 0.03   | 0.04   | 0.82     | 0.2           |
| Basin           | PY1  | O3w-S1 | 1.15                 | 98.47   | 0.69   | 0       | 0      | 0.04   | 0.67     | 0.18          |
| Basin           | Z10  | O3w-S1 | 0.8                  |         |        |         | 0      | 0      | 0.67     | 0.18          |
| Externai Basin  | YY   | O3w-S1 | /                    |         |        |         |        |        | N2, CO2   |               |

The content of nitrogen and carbon dioxide is indicative of the preservation conditions of shale gas reservoirs. For the southern marine strata, the nitrogen in the nitrogen-rich gas mainly comes from the atmosphere. It characterizes the degree of connectivity between the underground and the surface and is a direct reflection of oil and gas. Index of preservation conditions. The Ordovician, Cambrian, and Sinian systems remain in the Sichuan Basin and parts of its surrounding areas, and the regional caprock Silurian is incomplete, and the burial is shallow, and the overall preservation conditions are poor, resulting in a generally high nitrogen content in natural gas. Well Zhao 101 and Well Yuye 1 are
mainly nitrogen and carbon dioxide gas, and the content of natural gas is not high, indicating that the gas reservoir is damaged, which is caused by the penetration of atmospheric nitrogen and carbon dioxide gas into the ground (Table 3).

4.4. Gas content characteristics
On-site analytical gas volume is one of the most direct indicators to identify the sweet layer. However, exploration practice has shown that there is uncertainty in the application of GIP to identify shale gas enrichment layers. Based on the rapid on-site desorption instrument independently developed by Sinopac Wuxi Institute of Petroleum Geology, based on the on-site desorption of typical shale gas in southeastern Sichuan, the index IDR index, total gas content (GIP) and initial The combined application of the Dissipation Index (IDR) can better identify the sweet spots of shale gas and avoid the lack of single factor identification of sweet spots. The WY23-1 high gas content and high initial emission horizons are mainly concentrated in ③ small layer, ② small layer, ④ small layer and ① small layer. Among them, at the bottom of ③ small layer, the GIP and IDR are relatively large, which is a geological best layer of sweet layer (Figure 3). The on-site horizontal wells of Well WY23-1 mainly traverse the small layer ③, and the on-site fracturing obtains high-yield commercial airflow, which has achieved good results.

4.5. Identification of the carbon isotope value characteristics of desorbed gas to determine the shale gas production stage and remaining gas content
The carbon isotope fractionation effect of alkanes generally exists in the desorption process of shale gas. In the process of on-site analysis, the carbon isotope values of methane and ethane of the gas increase with the increase of the gas desorption rate. Taking the carbon isotope characteristics of methane in the desorbed gas from Well Jiaoye 11-4 as an example, the carbon isotope value has an obvious fractionation effect with the desorption time. The methane carbon isotope value gradually changes from an average of about -30‰ at the beginning to -5‰ at the end of desorption. In the actual desorption process, the carbon isotope obviously presents two stages, which is closely related to the second-order desorption of shale gas field. In the first-order desorption stage, the carbon isotope value slowly rises with time, and the amount of desorbed gas steadily increases. In the second-order desorption stage, the carbon isotope value rises rapidly with time, and the desorbed gas rises from rapid to slow rise, and finally in the desorbed gas methane When the carbon isotope changes to about -5‰, it is the final stage of the desorption process, and the amount of desorption basically no longer increases. During the desorption process of shale gas, its methane carbon isotope composition is a value that changes with the gas desorption rate. Therefore, we can not only use the lowering of the methane carbon isotope value to judge the effect of fracturing, but also establish a certain regional page through experimental measurement. The relationship between the desorption rate of rock gas and the carbon isotope composition of methane can also be used to predict the remaining resources of shale gas wells (Figure 4).

Figure 3. "G&I two-factor method" to identify the WY23-1 sweet layer

Figure 4. Methane carbon isotope values and desorption gas change with desorption
5. Conclusions
The Wufeng-Longmaxi Formation shale in the Sichuan Basin and its surrounding areas is rich in organic matter. From the upper section of the Lower Silurian Longmaxi Formation to the Upper Ordovician Wufeng Formation, the TOC value generally shows an increasing trend, kerogen type I, and the overall Maturity-over-mature stage. The total gas content and desorbed natural gas components are the most direct methods to identify shale gas sweet spots; the first sample carbon isotope value and its characteristics can predict shale gas rich layers, which is an effective method to identify shale gas sweet spots. Shale gas components and carbon isotope values jointly identify the genetic type of shale gas. The characteristics of cheese and carbon isotope and carbon isotope characteristics of shale gas can be used as effective means for gas source comparison. Natural gas in the Wufeng-Longmaxi Formation in Jiaoshiba area belongs to Self-generation and self-storage, the crude oil cracked gas at the main high thermal evolution stage has a high proportion of methane, has not been affected by atmospheric underwater seepage, and has good storage conditions. The sweet layer has the characteristics of plateau gas content (GIP) and high initial dissipation rate (IDR), which has a predictive effect on the productivity of shale gas wells; the carbon isotope value of methane has obvious fractionation effect with the desorption time, and the carbon isotope value and desorption of methane The gas volume has obvious changes with the desorption time, which can be used to predict the shale gas production stage and the remaining gas content.

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