Study on the characteristics of gas-generating reservoir-caprock assemblages and gas traps in coal measures in Fuxin Basin

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Abstract. As an unconventional natural gas reservoir, sand body gas has unique characteristics. The paper takes Fuxin Basin as the research object and carries out systematic research on the characteristics of sand gas generation reservoir cap combination. The main controlling factors are analyzed for the trap characteristics of the sand gas reservoir in the main formation. The results show that there are two types of gas source rocks in Fuxin Basin, namely, dispersed organic matter and concentrated organic matter reservoirs, which are mainly composed of two sets of strata. The first set is the lower channel sand bodies of the Fuxin Formation, and the second set is the third member of Shahejie Formation, The second alluvial fan-fan delta sand body. The caprock of Fuxin Formation is mudstone and siltstone in the middle and upper part of this group. The cover layer of Shahai Formation is mudstone and siltstone in the fourth member of Shahe Formation, with dense and uniform development in the whole area and stable sedimentation. Sand gas traps in Fuxin Basin are mainly controlled by two types of traps: structural traps and lithologic traps.

Keywords: Fuxin Basin; sand body gas; source-reservoir cap; gas reservoir trap.

1. Introduction
Coalbed methane is unconventional natural gas that is produced in and stored in coal seams. The main component is methane, which is a high-quality, clean energy and chemical raw material [1-3]. China is rich in coal resources, with coal reserves of about $1 \times 10^{12}$ t, of which bituminous coal accounts for more than 80%. According to preliminary estimates, the burial depth is less than 2000m and the coalbed methane resource is $3.5 \times 10^{13}$ m$^3$, so coalbed methane has a strong resource base as an associated mineral [4-6].

The Fuxin Basin is located in the west of Liaoning Province and is under the jurisdiction of Fuxin and Jinzhou[7]. It is bounded by the Yiwulushan Mountain Range in the east and the Songling Mountain Range in the west; Shala is bounded in the north and Daling River in Yi County in the south [8-9]. In coalbed methane development, sand gas in coal measures is also a natural gas resource that cannot be
ignored. Geological drilling oil and gas logging in the Fuxin mining area shows that 82% of the boreholes have full sand gas distribution layers and many layers. Each section from the Fuxin Formation to the Shahai Formation has varying degrees of oil and gas display [10]. The gas reservoir is mainly dominated by overpressure, and the well pressure can reach dozens of atmospheres. The fourth member of the Shahai Formation in the Fuxin Basin is dominated by mudstone and siltstone, which are widely distributed and rich in biological fossils, which are both gas-generating layers and ideal caprocks, forming very good combination conditions of generation, storage and capping[11 -13]. The thesis takes the main oil and gas reservoirs in Fuxin Basin as the research object, combined with the physical properties of the reservoir, to study the formation, reservoir and cap combination affecting the target layer, and discusses the trap characteristics of sand gas reservoirs. The development of gas resources provides theoretical guidance.

2. Geological background
The tectonic location of the Fuxin Basin is in the eastern Liaoning platform and the Yanliao platform fold belt in the southern Inner Mongolia axis. The east side of the basin is the Daba-Jinzhou fault, and the west side is the Xinglonggou-Aolamahuang fault. The northern part is connected to the Erlangmiao fault in the Inner Mongolian axis. The Fuxin Basin is a typical continental rift basin. The fault structures on the east and west sides of the basin play a decisive role in the formation, development and evolution of the basin (Figure 1) [10].

![Figure 1. Regional structure map of Fuxin Basin (according to Wang)](image)

The Fuxin Basin is a north-north-east-trending faulted basin. The former Sinian or Sinian strata were the basement, which was deposited in the Late Mesozoic strata [14]. The main sand body gas reservoirs are the Shahai Formation and the Fuxin Formation. The Lower Cretaceous Shahai Formation is distributed in the whole area of the Fuxin Basin and the reservoir structure is stable. It is divided into four sections according to lithological characteristics, from bottom to top: the first section of sand: mainly conglomerate and sandstone, with siltstone and mudstone. The section is purple-red or gray-
purple to the south of Ai You, and gray and gray-green to the north. The thickness is about 150m. The second member of Sha: mainly composed of gray-green, gray-white conglomerate and sand-conglomerate, with siltstone and mudstone. The thickness is about 150m. Section 3 of Sha: Coal-containing section. The lower part is the fan delta facies composed of gray sandstone, fine sandstone, gray-black siltstone and mudstone, the middle is the fan-front flood plain sedimentary facies composed of gray and dark gray sandstone with fine conglomerate and siltstone, and the upper part is gray and light gray Fan delta facies composed of sandstone, siltstone, mudstone, charcoal mudstone and coal. This section contains recoverable coal seams in Jiudaoling, Qinghemen, Aiyou and Dongliang areas. The thickness of the formation in this section is about 500m. The fourth member of the Sha: mainly composed of gray, dark gray, gray-black mudstone, siltstone, and sandy mudstone, with sand conglomerate, conglomerate, and thin sandstone, containing a large number of mollusk fossils, with a thickness of 240-900m. Because of its thin lithology and the development of the whole area, it is a good regional cover and a sign of regional comparison.

Lower Cretaceous Fuxin Formation: It is the main coal-bearing stratum, and its lithology is divided into upper, middle and lower parts. Lower part: mainly grayish white and light gray sandstone and mudstone, with coarse sandstone and conglomerate. Central: It is gray, light gray mudstone, sandstone and siltstone. It contains 5 large recoverable coal seams of Gaode, Taiping, Zhongzhong, Sunjiawan and Shuiquan. It is developed in the whole area and is the main mining target of Fuxin mining area. Upper part: It is gray-green mudstone, siltstone and gray-white conglomerate, with unminable coal seam. The sedimentary lithology and lithofacies of the Fuxin Formation vary greatly, and the sedimentation is unstable, which is a river and swamp environment.

3. Characteristics of gas-generation reservoir-caprock assemblage of sand body in Fuxin Basin

3.1. Gas source rock
Rocks that can generate hydrocarbons are called gas source rocks [15]. Unaffected by the occurrence, thickness, environment, and lithology, any organic substance can generate gaseous or liquid hydrocarbons as long as it has conditions such as temperature and pressure [16-17]. This fluid ore body is migrated by the action of static pressure and dynamic pressure, and gathers at favorable locations to form a gas (oil) reservoir.

There are two types of gas source rocks in Fuxin Basin, namely dispersed organic matter and concentrated organic matter, which are produced in swamps, deep lakes, shallow lakes and delta environments. The terrestrial plants and aquatic organisms that are sources of organic matter are the precursors for the formation of hydrocarbons, and their growth environment reflects the hydrocarbon environment. The rich animal and plant molecules in the formations of Fuxin Formation and Shahai Formation in Dongliang District are the main source of organic matter. They are distributed in the coal seams, mudstones, charcoal mudstones, and oil pages in the third, fourth and Fuxin formations of Shahai Formation.

3.1.1. Concentrated organic matter. Coal seam is the residual material in the evolution process of organic matter. Due to the different metamorphism degree, the coal type is also different, and the reserves are rich, and they are stored in the Fuxin Formation and Shahai Formation respectively. In the process of coal formation, with the continuous deepening of coalification, the output of hydrocarbon gas also continues to increase, that is, the stage from peat to lignite is an immature stage (Ro, max<0.5%). The hydrocarbons produced in this stage have a high methane content and no or little heavy hydrocarbon gas. Generally speaking, the hydrocarbon production capacity is very low and belongs to dry gas. From the long flame coal to the lean coal stage (0.5%<Ro, max<1.9%), this stage is a mature stage, and hydrocarbon gas begins to be produced in large quantities, still mainly methane. The methane content reaches the highest value in the coking coal stage, and the heavy hydrocarbon content also increases significantly. The coking coal and part of the fat coal stage are the periods with the highest yield of heavy hydrocarbons. At this stage, it is also the main production stage of liquid hydrocarbons (oil),
producing the most oil at the stage equivalent to the fat coal. It can be seen that the biggest feature of this stage is the simultaneous generation of oil and gas. From the perspective of the entire Fuxin Basin, the coals in Weidongliang District have fat coal and coking coal, so they have the characteristics of coexistence of oil and gas.

3.1.2. Dispersed organic matter. The angry rocks are gray-green, gray, dark gray, gray-black mudstone, charcoal mudstone and oil shale. The ability to be angry is controlled by the degree of evolution and the depositional environment. Mudstone is distributed in the formations of each group and is the main source of gas.

The Shahai Formation is the second expansion period of the lake basin, forming a set of coarse and fine clastic rocks. The fourth member of the Shahejie Formation is a shallow lake-semi-deep lacustrine sediment in a reduction-strong reduction environment. The lithology is dominated by dark mudstone, which is the most developed layer of dark mudstone. The Fuxin Formation is a swamp environment, which mainly contributes to the formation of dispersed organic matter, but the stratigraphic phase changes sharply in the lateral direction, and each sedimentary sequence is from coarse to fine, with obvious rules. Due to the continuous activity of basin edge faults, the low-lying watersheds that are divided from each other receive abundant land-based materials, thus accepting the deposition of mudstones and coal beds of varying thickness.

3.1.3. Geochemical characteristics. (1) Abundance of organic matter

Organic matter abundance is one of the indexes to evaluate the gas source rock, mainly from the organic carbon content (TOC), chloroform asphalt "A", total hydrocarbon content and hydrocarbon generation potential for comprehensive evaluation. The organic matter abundance of the Fuxin Formation, Sha1 and Sha2 is lower than that of Sha4 and Sha3, which is not a good gas source rock. According to the classification criteria of oil-generating rocks, Sha3 is the better gas source rock. The fourth segment is better-the best source rock (Table 1).

| Types          | TOC (%) | "A" (%) | Total (ppm) | S1+S2 (Kg/t) |
|----------------|---------|---------|-------------|--------------|
| Non-oil rock   | <0.40   | <0.015  | <100        |              |
| Poor           | 0.40-0.60 | 0.015-0.05 | 100-200    | <2           |
| better         | 0.60-1.00 | 0.05-0.10  | 200-500     | 2.00-6.00    |
| Good           | 1.00-2.00 | 0.10-0.20   | 500-1000    | 6.00-20.00   |
| best           | >2      | >0.20     | >1000       | >20          |
| Fuxin Formation | 2.86 | 0.011   | 100.7       | 5.26         |
| Sha 4          | 2.98 | 0.126   | 523.42      | 7.99         |
| Sha 3          | 2.78 | 0.187   | 96.35       | 7.77         |
| Sha1-2         | 0.48 | 0.038   | 115.29      | 6.40         |

(2) Nature and type of organic matter

The sources of organic matter are mainly terrestrial organisms and lake aquatic organisms. The mixture of the two organisms is either land or lake, which determines the three main types of organic matter types, III (humus type), II B (humus-humus type), II A (humus-humus type), which determines The hydrocarbons generated in the area are mainly gaseous hydrocarbons and a small amount of liquid hydrocarbons. Identifying the type of organic matter is the basic parameter for evaluating gas fields, and comprehensive evaluations are made using kerogen microscopy, pyrolysis, and kerogen element analysis. The kerogen identification results of Fushen 2 well show that all sections of Shahai Formation are mainly type III (Table 2).
Table 2. The change of microcosmic composition of kerogen in Fushen 2 well

| Lipids(%) | Chitin(%) | Vitrinite(%) | Inert(%) | Type index(%) | Type | Samples |
|-----------|-----------|-------------|---------|---------------|------|---------|
|           |           |             |         |               |      |         |
| Sha 4     | 0         | 27          | 65      | 8             | -43  | III     | 1       |
| Sha 3     | 0-37      | 15-76       | 22-66   | 0-50          | -69-39 | III | 6 |
| Sha 1-2   | 0         | 57          | 43      | 0             | -36  | III     | 1 |

(3) Organic matter maturity

Organic matter maturity is an indispensable element in evaluating gas source rocks. Due to different geological conditions, thermal evolution history and maturity are also different. The evolution characteristics of organic matter in this area can be seen through the comprehensive chemical profile of hole 569 in Fuxin Basin and other test results (Table 3).

Table 3. Comparison table of various geochemical indexes above and below 826m in hole 569 of Dongliang District, Fuxin Basin

| Type | Above 826m | Below 826m | Coefficient of variation |
|------|------------|------------|-------------------------|
| TOC% | 1.25       | 2.74       | 2.19                    |
| “A”% | 0.021      | 0.14       | 6.67                    |
| Total | 34         | 396        | 11.65                   |
| S1+S2 | 0.33       | 58.74      | 178                     |
| H/C  | 0.87       | 1.08       | 1.24                    |

The various indicators show a clear change law around 826m. As the depth increases, the temperature and pressure increase, the total hydrocarbon content, the content of asphalt "A" and other indicators all increase, reflecting the increase with depth. The law of increasing maturity.

Mirror coal reflectivity (Ro, max%) is an indicator that reflects the maturity of organic matter. The reflectance of mirror coal in the Fuxin Formation of Dongliang District is 0.38-0.45%, which is immature or close to maturity. According to the comprehensive analysis, the Zhifu Formation and the fourth member of the Shahejiejie Formation are low-maturity and better-generating rocks, and the third member of the Shahejiejie Formation, the first and second members of the Shahejiejie Formation are better-generating and better-generating rocks.

3.2. Reservoir

3.2.1. Reservoir type. Mainly refers to sandstone reservoir. All sand bodies with connected pores and certain storage space (porosity, permeability) can be used as oil storage and gas layers. According to the sedimentary environment, there are two main sets of sand bodies. The first set is the lower channel sand bodies of the Fuxin Formation, and the second set is the alluvial fan-fan delta sand bodies of the third member of Shahe, the first and second members of sand.

The lower channel sand body of the Fuxin Formation: It is the main oil-bearing and gas-bearing section, mainly composed of medium and coarse sandstone and mudstone interbedded with sand and conglomerate. According to the analysis of boreholes, there are 4 good sand bodies, with 1, 2, 3, 4 sand bodies from top to bottom (Table 4).

Table 4. Changes in thickness of sand body in the lower part of Fuxin Formation

| Sand No. | Min-Max thickness (m) | Maximum thickness of single layer (m) | Number of layers |
|----------|-----------------------|--------------------------------------|-----------------|
| 1        | 1.18-51.13            | 19.90                                | 1-6             |
| 2        | 1.10-62.90            | 18.00                                | 1-7             |
| 3        | 1.15-37.15            | 30.20                                | 1-17            |
| 4        | 4.25-29.50            | 29.50                                | 1-8             |
Alluvial fan-fan delta sand bodies of the third member of the Sha, the first member of the sand, and the second member of the sand: it is the main reservoir section in this area, with a sand content of 69%. According to the analysis of drilling data, there are 10 good sand bodies (Table 5).

Table 5. Statistical table of sand body changes in the third member of Shahai Formation

| No. | Cumulative(m) | Maximum thickness of single layer(m) | average thickness(m) | Change |
|-----|---------------|-------------------------------------|----------------------|--------|
|     |               |                                     |                      | Average | Max   |
| S1  | 85.81         | 38.10                               | 22.65                | 3-7     | 10    |
| S2  | 47.57         | 38.10                               | 22.65                | 3-7     | 10    |
| S3  | 42.75         | 30.92                               | 13.41                | 2-4     | 6     |
| S4  | 35.05         | 35.05                               | 12.70                | 1-3     | 4     |
| S5  | 25.43         | 21.83                               | 9.22                 | 1-2     | 4     |
| S6  | 57.61         | 43.82                               | 14.58                | 1-2     | 6     |
| S7  | 52.84         | 20.00                               | 15.51                | 1-5     | 10    |
| S8  | 47.99         | 47.99                               | 17.01                | 1-4     | 6     |
| S9  | 46.40         | 23.34                               | 20.43                | 1-4     | 5     |
| S10 | 34.65         | 8.00                                | 17.90                | 3-6     | 7     |

3.2.2. Reservoir physical characteristics. Among the 94 samples of the Shahai Formation in the Fuxin Basin, 74 have a permeability of less than 1md, accounting for 79%, 5 have a sample of 1-10md, accounting for 5%, 9 have a sample of 10-100md, accounting for 9.6%, and 100-1000md There are 3 blocks accounting for 3.2%. Of the 10 samples in the Fuxin Formation, 3 of them accounted for 30% between 1-10md, 4 of them accounted for 40% of 10-100md, 2 of them accounted for 20% of 100-1000md, and 1 was greater than 1000md accounts for 10%. This shows that the reservoir has poor physical properties. The Shahai Formation is a low-medium porosity and ultra-low permeability reservoir, and the Fuxin Formation is a medium-high porosity and moderate permeability reservoir (Figure 2).

Figure 2. Distribution characteristics of porosity and permeability of Shahai Formation and Fuxin Formation

According to the analysis of the reservoir physical properties of each group in this area, most of the reservoirs in the Shahai Formation are poor reservoirs, and there are few medium reservoirs and good reservoirs. Poor physical conditions are not conducive to the formation of good oil and gas reservoirs, and can still be used as a reservoir for natural gas. The physical properties of the Fuxin Formation reservoir are better than that of the Shahai Formation, which can be regarded as a better reservoir.

3.3. Capping

The caprock is a rock layer located above the reservoir to prevent gas from escaping upward. The area is mainly mudstone and silty mudstone. The caprock of Fuxin Formation is mudstone and siltstone in the middle and upper part of this group. The thickness is 5-70m, and the continuity is good. The whole area is distributed. The local thickness is not large and can be used as a cover.

The cover layer of Shahai Formation is mudstone and siltstone in the fourth member of Shahe Formation, which is dense and uniform, with an average thickness of 250-450m. The whole area is
developed and the sedimentation is stable, which can be used as an ideal regional cover layer. A good cap layer does not determine its thickness, but depends on the displacement pressure of the cap layer and the degree of fracture development. The higher displacement pressure makes the power of oil and gas escape cannot reach the displacement pressure of oil and gas into the cap layer. May be closed. In the mudstone samples of 374m in Kongfuxin Formation and 465.50m in Shahai Formation of DT4 in this area, the maximum pore throats are 0.1186 and 0.0382 um, and the displacement pressures are 8.6468×10^5 pa and 31.3468×10^5 pa.

4. Main controlling factors of traps in sand gas reservoirs

4.1. Combination

The source-reservoir-cap combination and the organic matching between the three are essential conditions for gas reservoirs. According to the vertical sequence, the sand body gas reservoir combination in Fuxin Basin can be divided into: lower combination and upper combination.

(1) Lower combination

Refers to the combination of the formation of the Shahai Formation. This group of mudstones is developed, and the natural gas generated by it can enter the sand bodies with better physical properties, and under the conditions of good sealing of the cap rock, it can form an autogenous storage combination. In addition, the mudstone of the fourth member of the Shahejie Formation is also a good gas generating layer, forming a regional gas generating layer and a cap layer.

(2) Upper combination

A set composed of Fuxin group. It is composed of middle and upper mudstones as capping layers, composed of river sand bodies, mudstones, charcoal mudstones, and coal beds. Because the regional distribution of mudstones in the Fuxin Formation is far less than the scale formed by mudstones in the fourth member of the Shahejie Formation, it can only form a local source-reservoir-caprock combination.

4.2. Trap

Sand gas traps in Fuxin Basin are mainly controlled by two types of traps: structural traps and lithologic traps. Among them, structural traps are mainly anticline traps and fault traps. The synsedimentary anticline structure is the main structure in the Dongliang area, and it is inherited. Although it is an ideal anticline trap from the perspective of traps, the synsedimentary anticline has the characteristics of thin top and thin wing thickness, which makes Fuxin The coal seam of the formation has been eroded and eroded, so that the gas of the Fuxin Formation, including part of the gas of the Shahai Formation, has been dissipated. Although the oil and gas in the Fuxin Formation is widespread, the possibility of forming an atmospheric reservoir is very small, and there may be some local undamaged traps. The surviving gas. The anticline trap is an ideal trap for the Shahai Formation, with an area of 10 km^2. The fault traps in the Fuxin Basin are mainly reflected in the influence of fault development, which destroys the integrity of the anticline and is cut into several fault blocks by the fault, thus blocking the gas migration and preventing it from enriching into the atmospheric reservoir. However, because the faults in this area are well sealed, and have the characteristics of continuous ups and downs and continuous ups and downs, they do not affect each other. Although it is not conducive to the gas preservation of the Fuxin Formation, it can still be formed for the gas preservation of the Shahai Formation. Several fault traps, such as the combination of faults surrounding the hole.

Sand gas lithologic traps in Fuxin Basin are mainly traps composed of different permeability rock masses. Due to the majority of convex mirror-shaped sand bodies in Fuxin Formation, the formation of sand bodies inserted into gas-generating rocks is limited in scale. In addition, the formation at the top of the anticline is incomplete and the cap rock is not good. Most of the gas has been lost. The degassing effect is very strong, and the sand body gas reservoirs in the shallow Fuxin Formation have been damaged to a large extent. The Shahai Formation itself has formed a complete lithological trap, and the mudstone of the fourth member of Shahe Formation serves as a capping layer to better prevent the gas from escaping from the third member of Shahe Formation.
5. Conclusion
(1) There are two types of gas source rocks in Fuxin Basin, namely dispersed organic matter and concentrated organic matter, which are produced in swamps, deep lakes, shallow lakes and delta environments. The rich animal and plant molecules in the formations of Fuxin Formation and Shahai Formation are the main source of organic matter, which are distributed in coal seam, mudstone, charcoal mudstone and oil shale in the third, fourth and Fuxin formations of Shahai Formation.

(2) The reservoirs in the Fuxin Basin are mainly composed of two sets of strata. The first set is the lower channel sand bodies of the Fuxin Formation, and the second set is the alluvial fan-fan delta sand bodies of the third member, the first member and the second member of the member. The Shahai Formation is a low-medium porosity and ultra-low permeability reservoir, and the Fuxin Formation is a medium-high porosity and moderate permeability reservoir. The caprock of Fuxin Formation is mudstone and siltstone in the middle and upper part of this group. The thickness is 5-70m, and the continuity is good. The cover layer of the Shahai Formation is mudstone and siltstone in the fourth member of the Shahe Formation, which is dense and uniform, with an average thickness of 250-450m. The whole area is developed and the sedimentation is stable.

(3) Sand traps in Fuxin Basin are mainly controlled by two types of traps: structural traps and lithologic traps. Among them, structural traps are mainly anticline traps and fault traps. The syndepositional anticline structure is the main structure in the Dongliang area and the main controlling factor for structural traps. Lithologic traps are mainly traps composed of different permeability rock masses.

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