The enrichment law of tight sandstone gas in member 2 of Xujiahe in Yingshan gas field, Sichuan Basin

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Abstract. The enrichment law of dessets in Xujiahe formation of Sichuan Basin has become the core problem of tight sandstone gas reservoir. In view of this problem, taking the member 2 of Xujiahe Formation in Yingshan area of Sichuan Basin as an example, the author analyzes the main factors of enrichment of natural gas through the analysis of the basic geological features of sedimentary environment, reservoir, hydrocarbon source, structure and reservoir formation, and then discusses enrichment mode of natural gas. The results show that the reservoir forming conditions of member 2 in Yingshan area are superior, and the widely covered source rocks are developed, and the source rocks have good hydrocarbon generation potential. The sand bodies in the delta front with thick layers are deposited in member 2 of Xujiahe, which is distributed in large area, which lays the foundation for the development of high-quality reservoirs. The reservoir space types are various, mainly mainly including primary intergranular pores, dissolution pores and micro fractures, and the reservoir has good physical properties. The accumulation of natural gas in Yingshan structure is the result of coupling of the following factors: the development of high-quality reservoir controls the distribution of natural gas; the structural background is conducive to the enrichment of natural gas; the good matching relationship between faults and traps controls the differential accumulation of natural gas in the reservoir.

1. Introduction
With the continuous innovation of theory and technology, the exploration of tight reservoir oil and gas has made great breakthroughs[1-3]. Xujiahe formation of Upper Triassic in Sichuan Basin has the characteristics of "large area gas bearing and local enrichment"[4]. Natural gas exploration began in the early 1950s, and experienced three periods: structural gas reservoir exploration, lithologic gas reservoir exploration and tight gas reservoir exploration and development[5-8]. Many large gas fields, including Guang'an, Hechuan, Anyue and Penglai, have been discovered, forming exploration scenes of nearly trillions of square meters of reserves, of which the proved reserves of member 2 in Xujiahe account for 75% of the proved reserves of Xujiahe[9-11]. Zhao Zhengwang[12] and others pointed out that the enrichment of member 2 of Xujiahe gas in Central Sichuan is controlled by five main control factors, which are characterized by three reservoir forming modes and two types of oil and gas enrichment and
high-yield models. Combined with the factors of source rock, reservoir and structure, Tanghai et al.\cite{13} established the evaluation standard of the favorable area of tight sandstone in Xujiahe formation, and pointed out that the transition zone between central Sichuan and West Sichuan is the next favorable exploration area.

In recent years, although the Xujiahe Formation in Sichuan Basin has achieved abundant exploration results, its low reserve utilization rate and poor development effect have been the difficult problems to be solved in the exploration and development of Xujiahe formation. Because of the large difference of enrichment and high-yield factors in different regions, this paper takes member 2 of Xujiahe in Yingshan gas field in Central Sichuan as the research object, analyzes the conditions of natural gas accumulation, establishes high-yield enrichment model, and clarifies the distribution law of desert area, in order to indicate the direction for the next reserve utilization and effective well deployment.

2. Geological overview

Yingshan gas field, as a part of Sichuan Basin, has also experienced the sedimentary structural evolution history of Sichuan Basin. The marine strata dominated by carbonate rocks and the continental strata mainly composed of sand and mudstone in the upper Triassic to the Neogene have been deposited successively. It has experienced many structural movements such as Caledonian, Haixi, Indo China, Yanshan and Xishan. The Indosinian movement, Yanshan movement and Xishan movement have important influence on the formation of member 2 gas reservoir in Yingshan gas field. Yingshan structure is located in the north of Middle East Sichuan Basin, and belongs to Yilong structural group in the low and slow belt of the paleomiddle depression in northern Sichuan (Fig. 1), which is adjacent to the middle and gentle structural belt of the middle middle paleolong in Sichuan. The east end is adjacent to Huayingshan structural belt, and Gongshanmiao structure is in the West. It is connected with Longgang structure in the north, and Guangan structure in the south, and the Shaximiao Formation of Jurassic system is exposed on the ground.

Fig. 1 structural location and stratigraphic histogram of Yingshan gas field

The Xujiahe formation of the upper Triassic is a set of continental clastic rock deposits with alternating sand and mudstone interbedded by inland and lake in the middle of Sichuan Province. The burial depth is 2100-3600m and the thickness is 515-664m. It is slightly thinner from northwest to south in macro. The top of the system is in pseudo integrated contact with the Pearl thrust section of the Jurassic artesian well group, and the bottom is in contact with the lower Fulei kopo formation. According to the lithological combination and electrical characteristics, Xujiahe formation is divided into six sections from the bottom up. The member 1, 3 and 5 are mainly Lake biogas facies sedimentary, and the
lithology is mainly black shale and mudstone with thin-layer argillaceous siltstone, coal seam or coal line, which is the main source layer and cover layer of Xujiahe formation. Member 2, 4 and 6 are mainly littoral shallow lake delta deposits, with light gray, gray and white medium grain, medium to fine-grained lithic quartz sandstone, lithic feldspar sandstone and feldspathic debris sandstone as the main reservoir of Xujiahe formation oil and gas system. In the middle of Sichuan, Xujiahe Formation member 2, 4 and 6 are regional production layers, forming a "sandwich type" reservoir cap combination, which is conducive to the accumulation of natural gas. Large lithologic closed gas reservoirs such as Chong Xi, Guang'an and Hechuan have been discovered successively, showing a good exploration and development potential.

3. Reservoir forming conditions

3.1. Source rock conditions
The gas reservoir of member 2 mainly comes from the underlying member 1 of Xujiahe black shale. The member 1 of Xujiahe in Yingshan gas field is marine swamp environment, with shale as the main lithology sandwiched with a small amount of thin-layer siltstone and fine sandstone. The thickness of the first section is 20-90m, with an average of 45m, and gradually thinned from west to East. The organic carbon content of shale is 0.45% ~ 1.37%, with an average of 0.79%. The organic matter is mainly kerogen type III, and the Ro interval is 1.2% - 1.6%, which is in the high mature stage, which indicates that the quality of source rock is good, which provides sufficient gas source base for the overlying member 2 of Xujiahe.

3.2. Sedimentary environment
Xujiahe Formation in Yingshan area is a set of continental source clastic rock series with sand mudstone interbedding, with a total thickness of 515-664m and stable distribution. In Xui, xusan and Xuwu, lake facies deposition is the main one, mainly developed shale and coal seam, which is the main source rock; member 2, 4 and 6 are delta facies sand body mainly, and reservoir sand body is mainly developed. The member 2 of Xujiahe in Yingshan area belongs to delta front subfacies, with relatively developed reservoir, and the reservoir is mainly distributed in the underwater branch channel and estuarine dam sedimentary microfacies. From the core, most sandstone grains of member 2 of Xujiahe are coarse, mainly medium grains, and the separation and grinding circle are relatively good. Most of them are overlapped with small normal rhythm sand bodies. Common mudstones and carbon blocks are parallel bedding, oblique bedding and interlaced bedding, and the interlayer is in abrupt or scour contact. As for a single sand body, the grain size of rock from bottom to bottom is from coarse to fine, and the reservoir condition is changed from good to bad. The middle and lower parts of each sedimentary unit tend to develop relatively good reservoir sections.

3.3. Reservoir characteristics
The porosity of Xuhe second member of Yingshan structure is between 0.18% and 16.29%, and the sandstone porosity is mainly distributed between 3% and 9%, with an average of 6.14%. The high porosity reservoir (>10%) is developed; the permeability is between 0.00002-9.91md, generally between 0.01-1md, with an average of 0.084md, indicating that Xuhe gas reservoir of Yingshan structure is also a low porosity and low permeability reservoir (Fig. 4-11). The reservoir space of Yingshan gas field is mainly primary pore (intergranular pore), secondary pore (dissolution pore and heterobasic hole) and micro fracture(Fig. 2). The pore between grains is the pore space between debris particles. The most common intergranular pores in the study area are mainly composed of blade like chlorite, cementation along the pore wall, partial filling of second stage illite and half filling of primary miscellaneous base and residual inter particle holes. The internal dissolution pore is a dissolution pore formed in the clastic rocks in sandstone. The common is the dissolution pore formed by selective dissolution of the soluble part or the filler in the rock debris. The heteropore is a kind of microporous formed by recrystallization of the hydromica complex or the shrinkage of the mud complex during diagenesis. There are two kinds
of micro fractures, micro structural fractures and grain fracture patterns. The former is formed by
tectonic action, and is common in some wells in Yingshan area, while the latter is formed by compaction,
which is rare. Micro fractures generally extend along the edge of particles, with a small amount of
cutting particles, which are not filled basically. They are the main channel to communicate the porosity
of low permeability sandstone reservoir, and the effect on improving the permeability of sandstone is
obvious.

![Image of micro fractures, micro structural fractures and grain fracture patterns.](image)

Fig. 2 Reservoir space type member 2 of Xujiahe of Yingshan gas field

4. Main factors of gas accumulation

At present, the research on the factors affecting the fluid accumulation and distribution of oil and gas reservoirs is mainly focused on the process of reservoir formation and the factors of reservoir formation. Most of them think that the reservoir properties (including heterogeneity, physical properties, lithology, etc.), structural conditions, migration channels, traps, preservation conditions are the main factors. Based on the relevant research results at home and abroad, we take the accumulation process as the starting point to analyze the factors controlling the distribution of member 2 gas reservoir in Yingshan(Fig. 3).

4.1. Relationship between reservoir and oil and gas enrichment

The development of high quality reservoir controls the distribution of natural gas. The distribution range of member 2 gas reservoir in Yingshan structure is mainly controlled by effective reservoir. The high-yield gas wells are mainly distributed near the reservoirs with large thickness and high porosity, which belong to lithologic or structural lithologic gas reservoirs. The natural gas generated by source rocks in Xujiahe formation is preferentially migrated to the high-quality reservoir in Xujiahe formation. Although the late structural movement has played a certain role in adjusting the early gas reservoir, the high-quality reservoir developed in the dense sandstone is still the priority gathering field of natural gas. The production of single well also indicates that the high-quality reservoir controls the enrichment of natural gas.
4.2. Relationship between structure and oil and gas enrichment
The structural background is conducive to the enrichment of natural gas. The member 2 gas reservoir in Yingshan belongs to lithologic or lithologic structural gas reservoir. The combination of high structural part and high-quality reservoir is more conducive to the enrichment and high yield of natural gas. The adjustment of Xishan period formed the present structural pattern. In the three row structure, the first and second rows of structures are complete, independent anticline traps are developed, and oil and gas migrate horizontally along high-quality reservoirs and re enrich at the high structural height. The third row structure is monoclinic, which requires more stringent sealing conditions, which is not conducive to oil and gas conservation. Therefore, high-yield wells are mainly distributed in the first row and the second row structure.

4.3. Relationship between faults and oil and gas enrichment
Another important reason for the differential accumulation of oil and gas in member 2 gas reservoir is the development of the thrust fault of Xujiahe Formation in Yingshan structure, which mostly appears in the form of fault group, and generally consists of two faults which tend to extend in parallel in the opposite direction. The faults on plane are distributed in the northwest or northwest direction, mainly distributed in the near structural wings, controlling the structure shape. The fault is all reverse faults, with the characteristics of long extension, large drop difference and great change of fault inclination. The fault formation time is Yanshan Himalayan period, most of which are still active. The natural gas enrichment difference of the North South and South three rows structure formed by fault segmentation is obvious, the first row and the second row fault sand match is better, while the third row fault sand matching relationship is poor, which is not conducive to oil and gas enrichment. Obviously, the closed condition is an important control factor of Yingshan natural gas accumulation.

5. Conclusion
The reservoir forming geological conditions of member 2 member of Yingshan structure are better. The source rocks with good quality are developed in the first section of Xuhe. The sand bodies in the delta front with thick layers are deposited in member 2, which is distributed in large area, which lays the foundation for the development of high-quality reservoirs. The reservoir space types are various, mainly mainly including primary intergranular pores, dissolution pores and micro fractures, and the reservoir has good physical properties.

The accumulation of natural gas in Yingshan structure is the result of coupling of the following factors: the development of high-quality reservoir controls the distribution of natural gas; the structural background is conducive to the enrichment of natural gas; the good matching relationship between faults and traps controls the differential accumulation of natural gas in the reservoir.
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