Gas Accumulation Condition Study of the Permian Taiyuan Formation in Linxing Gas Field, Ordos Basin

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Abstract

Through a lot of analysis of the drilling, logging and experimental data, using oil and gas geology theory and hydrocarbon accumulation principle, the paper gave a systematic analysis of the hydrocarbon conditions and reservoir characteristics, reservoir cover conditions, reservoir and cap combination and gas accumulation condition patterns of the Permian Taiyuan Formation in Linxing gas field, Ordos Basin, initially revealed the gas accumulation condition and the main controlling factors of the gas field. Studies suggest that: multiple sets of Coal and shale in Benxi formation, Taiyuan formation and Shanxi formation are the main source rock of Taiyuan gas reservoirs, organic matter abundance of hydrocarbon source rocks is high, and hydrocarbon generation condition is favorable. Tidal flat and tidal deltaic phases developed in Taiyuan formation, quartz sandstone is the main reservoir, followed by quartz sandstone and debris sandstone, pore types are mainly residual intergranular dissolved pore and dissolved cuttings holes, showing an overall low porosity and permeability features of physical properties. the main control factor Pro Xing gas Taiyuan gas reservoir in Linxing gas field is reservoir properties, so the key for the next exploration and development is to look for relatively good reservoir, which is the quartz sandstone reservoir.

Keywords

Source Rock; Reservoir Rock; Accumulation Condition; Taiyuan Formation; Linxing Gas Field; Ordos Basin.

1. Introduction

Linxing gas field is located in the eastern margin of Ordos Basin, at the junction of North Shaanxi Slope and Jinxi flexural fold belt. It is another large upper Paleozoic gas field discovered after the Sulige, Yulin, Wushenqi, Zizhou, Daniudi, Mizhi and Shenmu gas field. To the north, Linxing gas field is adjacent to Shenmu and Daniudi gas field. To the west, it borders on Zizhou and Mizhi gas field (Fig. 1). The second section of lower Permian Taiyuan Formation (Tai-2 section) is one of the main gas bearing strata in this gas field. Up to now, the submitted proven geological reserves reached $730.52\times10^8m^3$, the technology recoverable reserves is $318.11\times10^8m^3$. It is expected that proven reserves can reach more than 100 billion cubic meters by the end of 2015. The past two years, nearly 20 preliminary prospecting well have been tested gas. Among them, the open flow of gas testing in Tai-2 section is between 4735 m^3/d -$148689m^3/d$ for the vertical well, and is up to $418928m^3/d$ for the horizontal well. Only in the year of 2014, Linxing gas field obtained the proven geological reserves nearly $700\times10^8m^3$, and the development potential is good. This had made a good start to CNOOC's landing more. The previous study results about reservoir foundation geology of the nearby gas field, such as Sulige and Daniudi gas field, are more. They include sedimentary, tectonic evolution [1-9], reservoir characteristics [10-12], accumulation condition and other studies [13-14]. But the study more focused on North Shaanxi Slope belt, west of the Yellow River. The relevant study of Jinxi flexural fold belt is very few, especially for the accumulation condition study of tight Sandstone in Taiyuan Formation. The difference of the large structural units will certainly cause some differences in the oil and gas accumulation. Therefore, it is very necessary to carry out targeted study for Linxing gas field by drawing on the previous study results of adjacent gas field. In this paper, a preliminary

analysis on the accumulation condition of Taiyuan Formation has been carried out. It is considered that the Taiyuan formation of Linxing gas field has excellent hydrocarbon source rock conditions and good reservoir-cap combination, which is the basic condition for the formation of large gas fields.

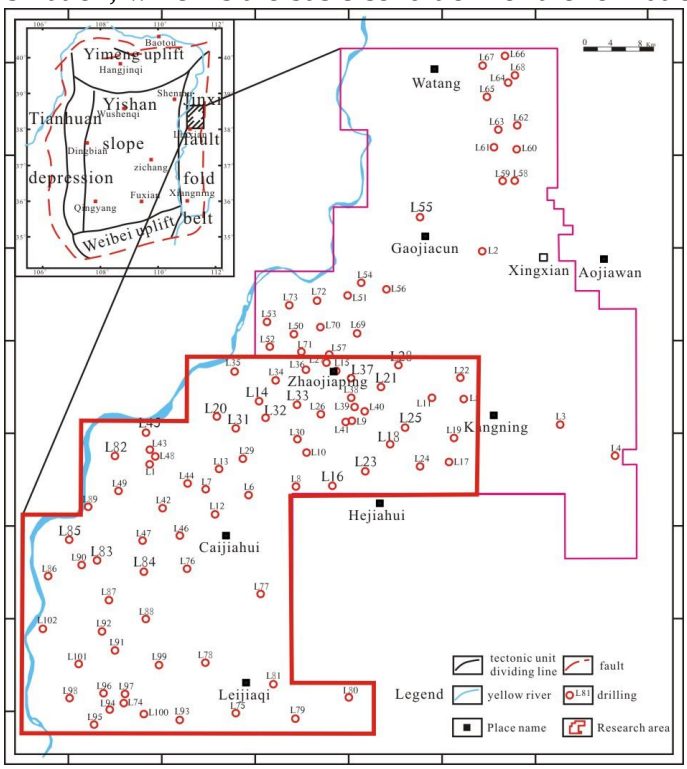


Fig.1 Sketch map showing structural location and block location of Linxing gas field

2. Hydrocarbon source rock condition

Previous exploration results and the present state of our exploration and practice prove that: widely covered hydrocarbon generation and large area gas supply in space have become a distinctive characteristic of upper Paleozoic hydrocarbon source rock of Ordos basin. The comparative study of gas source shows that multiple sets of coal seams and thick dark grey mud shale developed in the upper and lower strata of upper Paleozoic reservoir are the advantaged gas sources [4]. Linxing gas field is located at the center of hydrocarbon generation in the eastern margin of the Ordos Basin. In Benxi formation, Taiyuan formation and Shanxi formation, there are multiple sets of coal seams with different degrees of development. Among them, the No. 8+9 coal seam at the top of Benxi formation is a stable and widely distributed coal seam. The single layer thickness is between 2 and 15.5m (Fig. 2). The kerogen type of the No. 8+9 coal seam and the Taiyuan formation shale is mainly II_2 or III type. The hydrocarbon generating ability is strong, and the organic matter maturity (Ro) is 0.96% and 2.2%, which indicates that the source rock is in the mature and high mature stage. The organic carbon content (TOC) in the coal seams of Taiyuan formation and Benxi formation is between 43.71% and 78.87%, and the average level was above 63.06%. The TOC in mudstone is between 0.78% and 10.78%. The research results of the neighboring gas fields show that: the gas generation time of gas fields in this region is probably the late Jurassic and early cretaceous. The hydrocarbon generation intensity is between $28\times10^8 m^3/km^2$ and $35\times10^8 m^3/km^2$, cumulative hydrocarbon expulsion intensity is between $24\times10^8 m^3/km^2$ and $30\times10^8 m^3/km^2$. These gas fields already have the hydrocarbon generating conditions of forming large gas fields [14, 18].

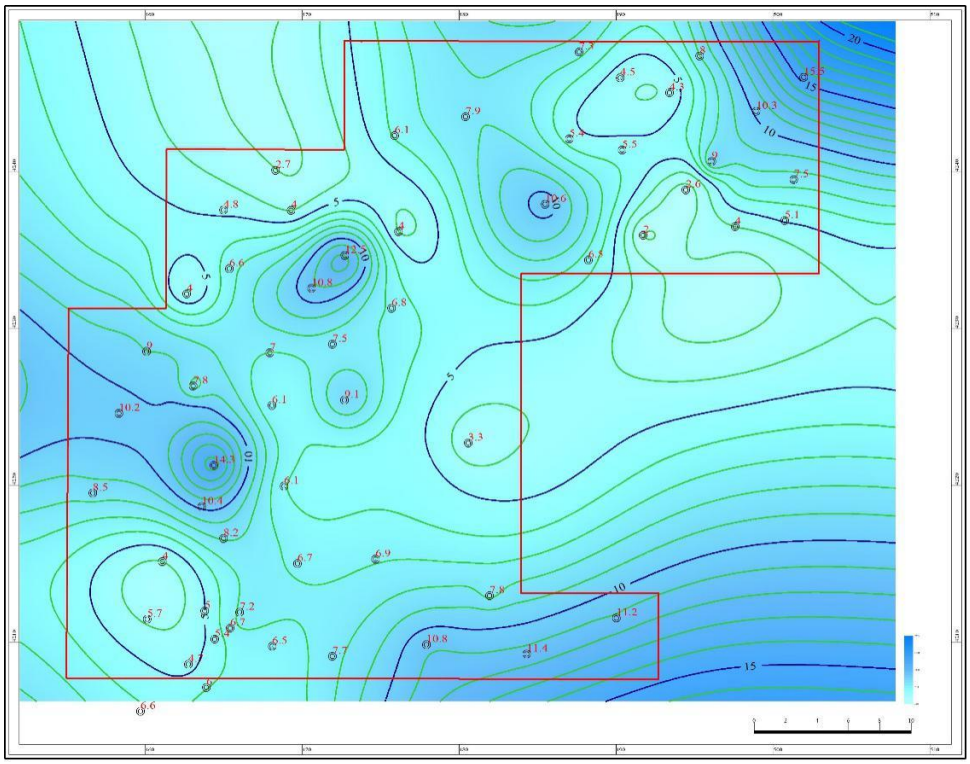


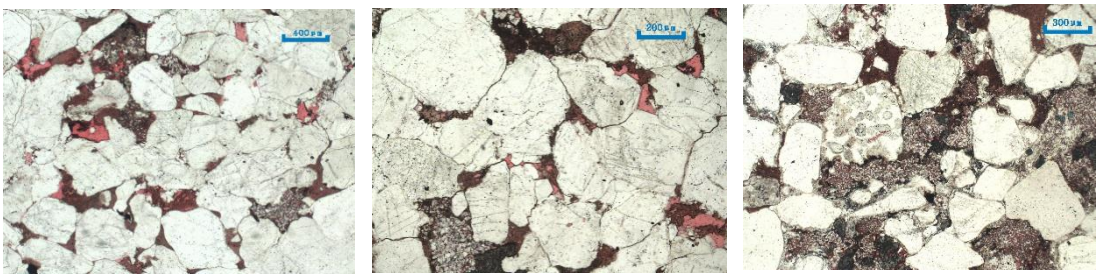
Fig.2 Contour map of 8+9 seam thickness of Linxing gas field

3. Reservoir condition

The sedimentary facies of Taiyuan formation in Linxing gas field are mainly epicontinental sea tidal-flat facies, tidal delta facies, barrier-lagoon facies and etc. The good reservoir is mainly distributed in the tidal channel, barrier sand bar micro facies, and has obvious characteristics of "facies controlled reservoir". The reservoir lithology of the study area is mainly debris quartz sandstone, which accounts for nearly 62%. Quartz sandstone in the proportion is second, also reached more than 35%. Also, there is a small amount of debris sandstone, accounting for about 3%. The residual intergranular dissolution pore and the debris dissolution pore are the main pore types in the study area, and the reservoir physical properties show obvious low porosity and low permeability.

3.1 Pore type

Through the statistics of 536 sandstone casting slice of Taiyuan formation in Linxing gas field, the pore types are mainly residual intergranular dissolved pore and debris dissolved pore. The dissolution is strong. Debris, feldspar and other unstable minerals are easy to be dissolved forming mold pore (Fig. 3). The dissolution of quartz is also common, it was usually dissolved in a harbor and serrated shape. Under the cathode luminescence, there are many quartz overgrowth side, calcite metasomatic debris, clay minerals and so on.



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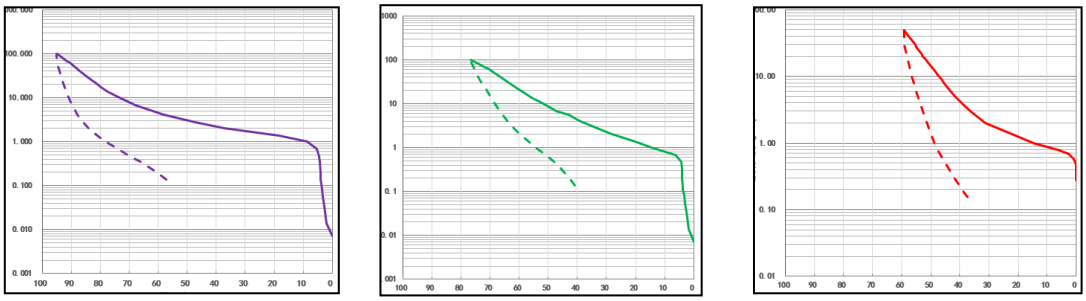


a b c

A: Quartz sandstone, residual intergranular dissolution pore. Matrix and quartz edge are dissolved. Porosity 12.1%, permeability 2.05mD, Lin A well, 1703.58m, cast sheet, ×50(-).

a: Lin A well, 1703.58m, pressure mercury curve

B: Debris quartz sandstone, debris dissolution pore. Matrix is dissolved. Porosity 8.2%, permeability 0.85mD, Lin B well, 1813.33m, cast thin section, ×50(-).

b: Lin B well, 1813.33m, pressure mercury curve

C: Debris quartz sandstone, filling intergranular pore. Early intergranular pores were filled with matrix. Porosity 4.3%, permeability 0.32mD, pro C well, 1833.54m, cast sheet, ×50(-).

c: Pro C well, 1833.54m, pressure mercury curve

Fig.3 Pore types and characteristics of Taiyuan formation of Linxing gas filed

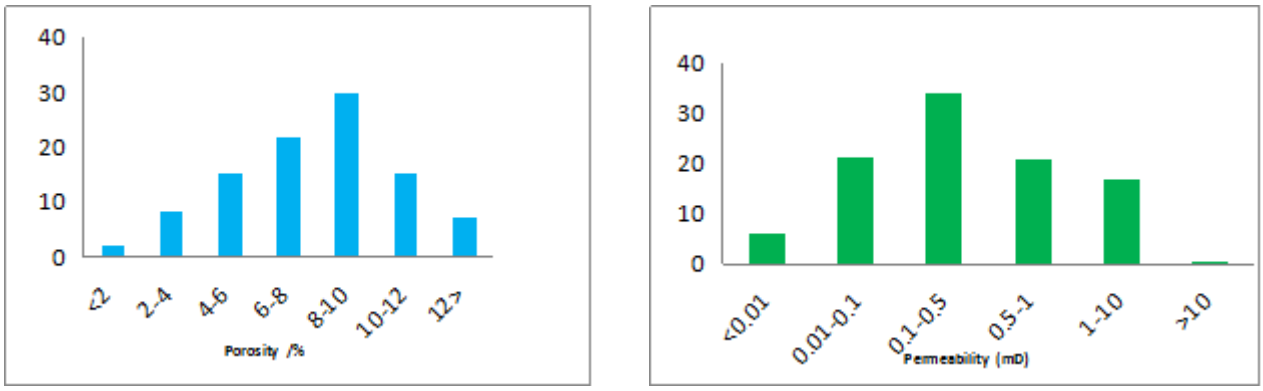
3.2 Pore structure characteristics

Through the analysis of 216 samples of mercury injection, the effective sandstone reservoir drainage pressure of Taiyuan formation is 0.16-1.97MPa, the median radius of throat channel is 0.12-0.55μm, and the maximum mercury injection saturation is 64%-85%, average 78.1%. The mercury withdrawal saturation of reservoir appeared relatively large differences, the distribution range is large, generally between 40%-96%, and the average value is 78%. Two different types of reservoir, such as debris quartz sandstone and quartz sandstone, or the same types of reservoir rocks all have different mercury injection curves (Fig. 3). Quartz sandstone mainly develops the residual intergranular pore. The capillary pressure curve showed a wide and gentle platform shape. The throat is development. The permeability is good. The most of the displacement pressure is less than 1MPa (Fig. 3a). But the throat of the debris quartz sandstone which is mainly based on the debris dissolution pore is not better than quartz sandstone, corresponding slope of pressure mercury curve will be increased, the displacement pressure is around 1MPa (Fig.3b). There are a small amount of dissolution holes of debris sandstone are filled with matrix, which causes the porosity to become smaller. Pressure mercury curve showed a large slope, the curve of the platform is relatively short (Fig. 3c).

3.3 Physical characteristics

Sedimentation and diagenesis have a great influence on the reservoir of Linxing gas field. The so-called "facies controlled reservoir" refers to the effect of the sedimentation on the reservoir. The basic rock fabric and the primary pore development situation of the sandstone reservoir in the same sedimentary facies is generally consistent. The diagenesis after sedimentation is also important for the formation of the pore structure of the reservoir. Through 1153 experiments, sample analysis showed that the porosity of sandstone reservoirs in Taiyuan formation is mainly in 0.4%-13.82%, the average is 8.2%, and the reservoir permeability is mainly distributed between 12.66mD and 0.02mD, with an average of 0.55mD (Fig. 4).

Objectively speaking, the reservoir condition of Linxing gas field is relatively poor. But in sedimentary facies belt with the development of tidal channel and barrier bar and in the favorable area of diagenesis, the coarse quartz sandstone and coarse debris quartz sandstone reservoirs are relatively well developed, which can be enriched to form a high-yield gas reservoir.



Left: the porosity distribution frequency histogram, the number of samples, 721;
Right: the permeability distribution frequency histogram, the number of samples, 721.
Fig.4 Physical properties of the Taiyuan Formation of Linxing gas field

4. Reservoir cap combination

Well matched reservoir cap assemblage is very important for natural gas accumulation. The Mud shale developed in the Benxi formation is stable in horizontal distribution and dense in lithology, which can be used as a regional base plate for gas reservoir of Taiyuan formation. The mud shale of Taiyuan formation and Shanxi Formation with stable distribution in the region has high organic matter abundance and hydrocarbon generating capacity, which can not only play the role of physical closure, but also has the role of hydrocarbon concentration closure. In addition, the top strata of Permian often developed in continuous and stable distribution of the red mud, can be used as a regional cap. A large set of continuous and stable distribution of purple red mudstone develop in the upper strata of Permian, which can be used as a regional cap. In the tight sandstone reservoir, the residual intergranular dissolution pore, intergranular dissolved pore and the debris dissolved pore are the main gas storage space, gas is filled into the pores in the process of hydrocarbon expulsion and then aggregated into a reservoir.

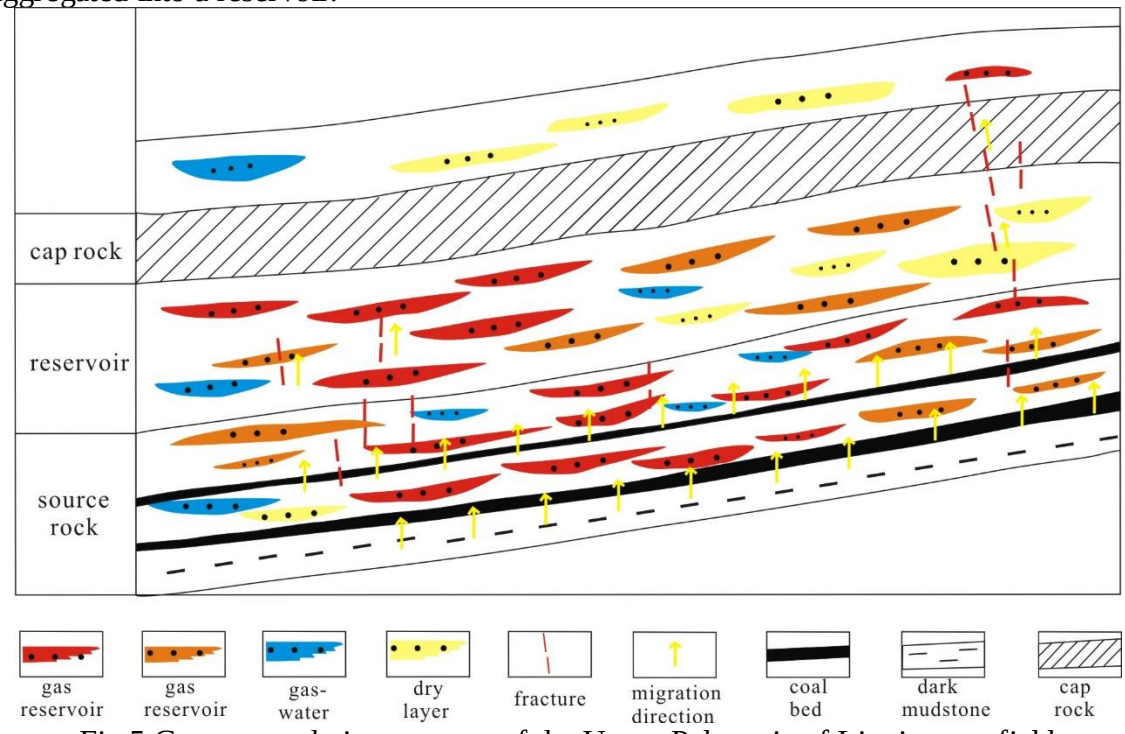


Fig.5 Gas accumulation patterns of the Upper Paleozoic of Linxing gas field

5. Main controlling factors of accumulation

Gas reservoir of Taiyuan Formation in Linxing gas field is typical lithologic trap gas reservoir with source reservoir cap assemblage, which has good hydrocarbon generating conditions, high efficient closure performance and favorable reservoir combinations. The main controlling factors of the gas reservoir can be summarized as "micro facies control reservoir, physical property accumulation". The development of tidal channels, barrier sand bar and other favorable facies belt directly controls the distribution of oil and gas reservoir, and the reservoir physical condition affected by late diagenesis determines hydrocarbon accumulation effect. Therefore, it can be said that the reservoir physical property is the most important controlling factor of gas accumulation in the Taiyuan formation of Linxing gas field. In the exploration and development work, it is the key to find the reservoir with good physical properties in the favorable facies, which is to find quartz sandstone reservoir. Needs to point out, because Linxing gas field is located in Jinxi flexural fold belt, so local structural development is unavoidable. Therefore, it does not eliminate the impact of structural factors on gas reservoirs. This is what we need to focus on in the late exploration and development.

6. Conclusion

1) No. 8+9 coal seam and mud shale of Taiyuan formation in Linxing gas field are the main source rocks of Taiyuan formation, the organic matter abundance is high, and the hydrocarbon generating condition is superior.

2) The sedimentary facies of Taiyuan formation in Linxing gas field are mainly epicontinental sea tidal-flat facies, tidal delta facies and barrier-lagoon facies. The lithology of reservoir is mainly dominated by debris quartz sandstone, quartz sandstone in the proportion is second, and also there is a small amount of debris sandstone. Residual intergranular dissolution pore and debris dissolved pore are the main pore types in the study area, and the physical properties of the pores are characterized by low porosity and low permeability.

3) The main control factors of gas reservoir in Taiyuan group is the sedimentary facies and reservoir properties. Therefore, the key to the next exploration and development is to search for the relatively good reservoir in the favorable facies zone, that is, the development of quartz sandstone as the main reservoir.

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