

Fine evaluation and favorable area prediction of deep source rocks in northern Songliao Basin

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Abstract. Focusing on Xujiaweizi fault depression, the geological conditions and geochemical characteristics of deep natural gas formation in the north of Songliao basin are evaluated, the natural gas resources are estimated, and the favorable areas are optimized. Shahezi Formation shale is a set of coal bearing sediments with high organic matter abundance (TOC is 1% ~ 12%), high over maturity (R_o is 1% ~ 4%) and shore shallow lake facies, which are mainly distributed in Xujiaweizi fault depression, Gulong-Lindian fault depression and Yingshan fault depression. The thickness, TOC, R_o and hydrocarbon generation of four third-order sequences with different lithology (mudstone and coal) are carefully evaluated for the Shahezi Formation shale in the deep layer of Songbei. The comprehensive evaluation shows that the mudstone thickness of Es4 member in Anda and Xuzhong areas of Xujiaweizi fault depression is large (150 ~ 525m), TOC is high (1% ~ 4%), thermal evolution degree is high (R_o is 1.2% ~ 3.4%), and gas generation intensity is high ($20 \sim 815 \times 108m^3 / t$), moderate buried depth (3000~4500m) and overlapping area of 756km². It is a favorable exploration area for natural gas and shale gas in Daqing Oilfield.

1 Deep geological features in Songbei

The deep strata in the north of Songliao Basin mainly include lower Cretaceous Huoshiling formation, Shahezi formation, Yingcheng formation and Denglouku formation from bottom to top. The basement is Carboniferous Permian (Fig. 1), belonging to volcanic eruption and clastic rock coal bearing deposition in fault depression period. Among them, the coal mudstone of Shahezi formation dominated by shore shallow lake facies is thick, with good hydrocarbon generation conditions and great resource potential. Among them, the coal mudstone of Shahezi Formation dominated by shore shallow lake facies is thick, with good hydrocarbon generation conditions and great resource potential. Among them, Xujiaweizi has discovered the Xushen gas field in the volcanic rocks of the Yingcheng formation, and has obtained industrial gasflow in several sets of formations such as Shahezi and Denglouku formations. There are also many exploratory wells that have seen oil and gas in Gulong-Lindian fault depression in the west and the Yingshan fault depression in the east [1-3].

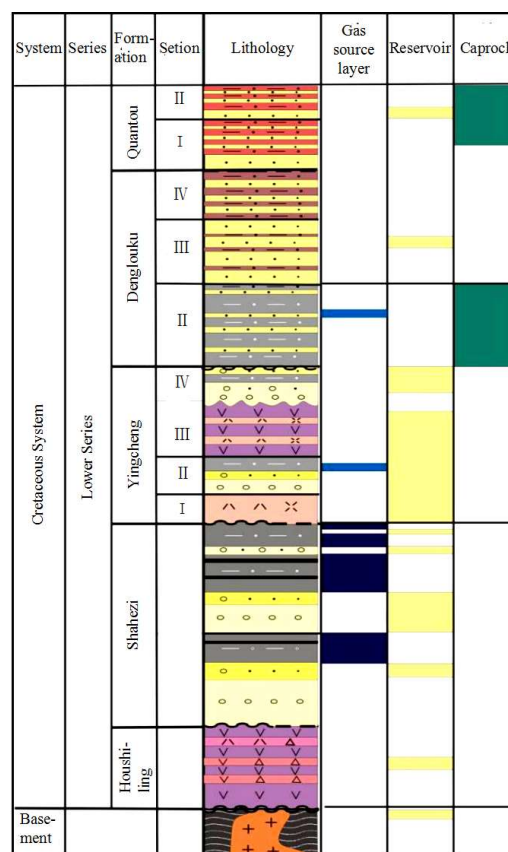


Fig. 1. Comprehensive column section of deep layer in northern Songliao Basin.

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2 Geochemical characteristics of deep source rocks in Songbei

The abundance of organic matter in gas-bearing shale not only determines the amount of shale gas generation, but also affects the occurrence and enrichment of shale gas, which in turn influences the resource abundance of shale gas [4]. For thermogenic shale gas reservoirs, with the increase of shale R_o , when $R_o > 1.1\%$, shale oil begins to crack and generate gas; when $R_o > 3\%$, the volume of gas generation is significantly reduced [5], moreover, the large reduction of organic matter is not conducive to the formation of adsorbed gas. Therefore, the range of R_o value of 1.1% ~ 3% is a favorable distribution area for thermally derived natural gas reservoirs. In this study, four sets of source rocks of deep Huoshiling formation, Shahezi formation, Yingcheng formation and Dengloulou formation were systematically analyzed and evaluated from three aspects of abundance, type and maturity in the north of Songliao Basin. In terms of region, the organic abundance index of Xujiaweizi fault depression located in the northern and central part of Songliao basin is higher than that of gulong, Yingshan and other peripheral fault depressions (Fig. 1). From the horizon, the geochemical index of Shahezi formation shale is better than other horizons as a whole (Table 1).

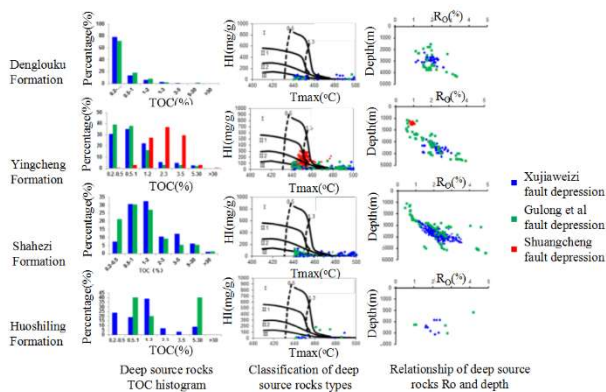


Fig. 2. Geochemical comprehensive evaluation map of deep source rocks in northern Songliao Basin.

Table 1. Evaluation table of geochemical characteristics of deep source rocks in northern Songliao Basin.

Formation	TOC	Type	R_o
Dengloulou	0.20% ~ 3.70% (0.48%)	III	1.13% ~ 2.62% (1.94%)
Yingcheng	0.21% ~ 14.25% (1.14%)	II ~ III	1.50% ~ 3.14% (2.25%)
Shahezi	0.2% ~ 76.6% (2.62%)	II ~ III	1.07% ~ 3.56% (2.22%)
Huoshiling	0.20% ~ 26.19% (2.11%)	III	1.62% ~ 2.39% (2.01%)

*Minimum~Maxmox (Average)

3 Fine geochemical evaluation of deep source rocks in Songbei

As the main component of natural gas generation and occurrence, a certain thickness of gas-bearing shale is the basic condition for the formation of natural gas enrichment areas, and it is also one of the important factors influencing the abundance of natural gas resources. The greater the thickness of shale rich in organic matter, the larger the scale of gas-bearing shale. At the same time, it can meet the needs of large-scale fracturing transformation and large-scale development of natural gas. When the thickness of gas bearing shale and the abundance of organic matter are determined, the area of gas bearing shale determines the amount of natural gas resources [6].

Due to the limited analysis data of core samples and the continuous formation information provided by logging data, organic matter has specific logging response because of its inherent physical and chemical properties. In recent years, a variety of logging combined evaluation methods have emerged: Based on the response characteristics of organic matter to sound wave, resistivity, density and natural gamma, an interpretation model is established to calculate the organic carbon value [7]. In this study, the Δ LOG method was used to accurately evaluate the total TOC of 137 exploratory wells in five fault depressions in the northern Songliao Basin, and effectively predict the total organic matter of source rocks in this area. Taking Well DS17 as an example, the average TOC of the source rocks of the four members of the Shahezi Formation is 4.93%, and the thickness of "mud-coated sand" interval is greater than 30m, which has the geological conditions for forming of self-generating and self-storing natural gas [8] (Figure 3). On this basis, in order to meet the needs of fine research and source rock feature evaluation, this study made a fine comparison of the source rocks of the Shahezi Formation in Xujiaweizi. The results show that three cycles of high-quality source rocks can be developed in each sequence set of Shahezi Formation, in which the TOC value of Shahezi Formation source rocks in the north of Xujiaweizi fault depression is mainly 1% ~ 3%, and the TOC value of some wells is greater than 3%. It is described that the source rocks of Shahezi Formation in the north of Xujiaweizi fault depression are getting better and better in abundance and thickness from north to south from the TOC well connection profile of source rocks of well DS3-SS6 (Fig. 4). High quality source rocks are principally distributed in Anda area, which is generally characterized by high abundance and good continuity of Sha4 member.

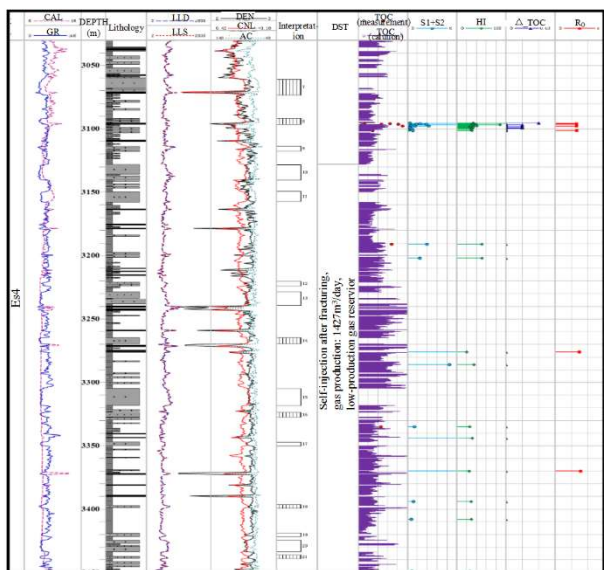


Fig. 3. Comprehensive histogram of Shahezi Formation in well DS17.

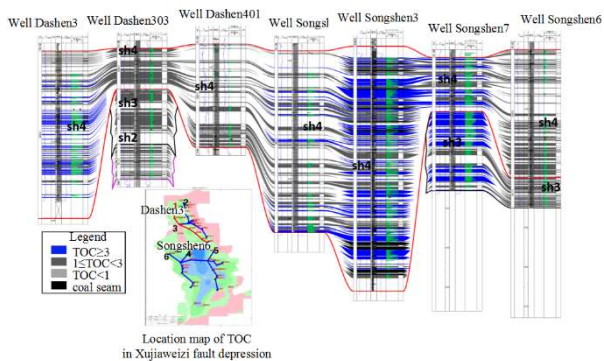


Fig. 4. TOC profile of Shahezi Formation source rocks in well DS3—SS6.

Based on the fine evaluation of single well and connected well of source rock, we calculate TOC results (removing oil-base mud pollution) and R_o according to all exploratory wells, mud logging, lithology, and well logging, besides draw the mudstone thickness map, TOC plane (Fig. 6) and R_o plane (Fig. 7) of the four sequences (sh1, sh2, sh3, sh4) of the source rocks of the Shahezi Formation in the Xujiaweizi fault depression, referring to the formation thickness and sedimentary facies trend (Fig. 5).

It can be seen from the figure that the distribution trend and characteristics of the thickness, abundance and maturity of the source rocks of Shahezi Formation in the four vertical sequences are not different, and the plane distribution characteristics are also similar, indicating that the sedimentary center of this area is stable, multi cycle high-quality source rocks are developed, and the overall performance is relatively high abundance coal bearing source rocks, of which SH4 layer is the best. Abundance of organic matter in the source rocks of the Shahezi Formation in Xujiaweizi is mainly distributed between 0.5% and 5.0% of the TOC classification thickness map.

Among them, the TOC value is mainly 1.0% to 2.0%, accounting for about 50% of the mudstone thickness of the whole Shahezi Formation.

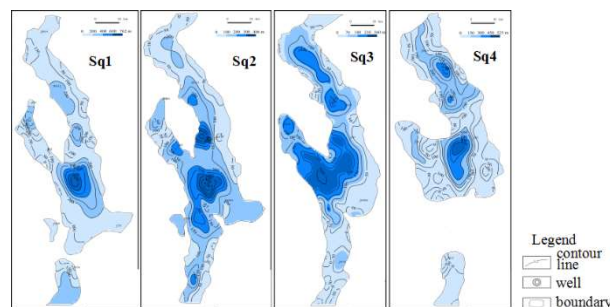


Fig. 5. Comparison map of mudstone thickness of four sequences of sourcerocks in Shahezi Formation of Xujiaweizi fault depression.

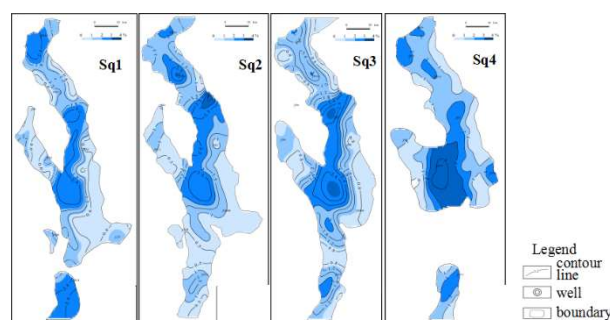


Fig. 6. TOC distribution comparison map of four sequence mudstone of Shahezi Formation in Xujiaweizi fault depression

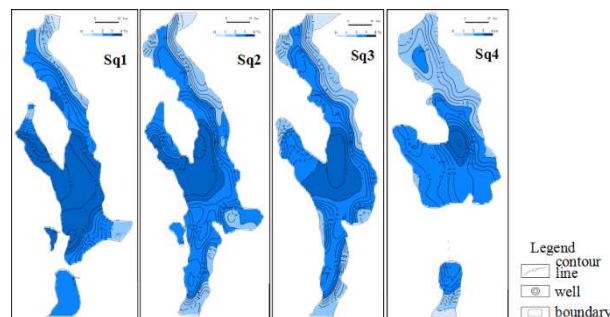


Fig. 7. R_o comparison map of sourcerocks of four sequences of Shahezi Formation in Xujiaweizi fault depression

4 Deep natural gas resource potential and favorable area optimization in Songbei

According to the latest drilling and seismic data, the mudstone thickness map is predicted, and the TOC value is calculated by logging curves, the measured R_o value is corrected for the thermal history, and the gas generation volume of the subdivision layer is calculated by the genetic method (Table 2). The calculation results show that the proportion of gas generation of four sets of source rocks is Shahezi Formation > Yingcheng Formation > Huoshiling formation > Denglouku formation. The gas generation intensity of source rocks in Shahezi Formation is high, more than 20 in most areas $\times 10^8 / \text{km}^2$, which

can form large and medium-sized gas fields [9 ~ 12] (Fig. 8).

Table 2. Calculation table of gas generation proportion of subdivision layers in Xujiaweizi fault depression.

Formation	Thickness of source rocks	TOC (%)	Gas generation (10 ² m ²)	Percentage (%)
Denglouku	0 ~ 200	0.36	1805	0.61
Yingcheng	0 ~ 300	0.78	9361	3.16
Es4 mudstone	0 ~ 600	1.63	52626	17.78
Es4 coal seam	0 ~ 80	60	19004	6.42
Es3 mudstone	0 ~ 300	1.39	44531	15.05
Es3 coal seam	0 ~ 60	55	14522	4.91
Es2 mudstone	0 ~ 500	1.53	61097	20.64
Es2 coal seam	0 ~ 45	53	7959	2.69
Es1 mudstone	0 ~ 800	1.19	72056	24.35
Es1 coal seam	0 ~ 60	57	9596	3.24
Huoshiling	0 ~ 100	0.72	3399	1.15
In total			295956	100

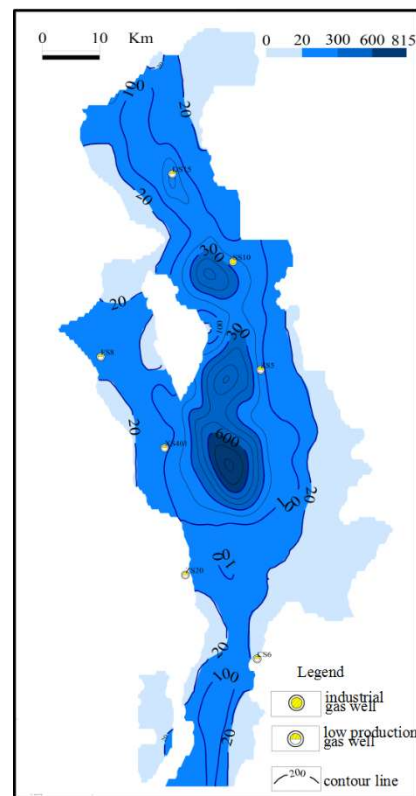


Fig. 8. Shale gas generation intensity plan of Shahezi

Formation in Xujiaweizi fault depression

Since the main part of shale gas is adsorbed gas, according to the principle of hydrocarbon generation and expulsion, part of the natural gas that not discharged but adsorbed in the source rock occupies the main source of shale gas. According to Pepper (1995), the gas adsorption coefficient is 0.02, and in the middle of the fault depression, the hydrocarbon generation intensity is more than $100 \times 10^8 / \text{km}^2$ which has shale gas resource potential.

The favorable natural gas area with TOC > 2% of mudstone in n the fourth section of Shahe in Xujiaweizi fault depression is 756km² and R_o is 1.1% ~ 4.0%, which has good natural gas resource potential; Shahezi Formation mudstone has high gas generation intensity, ranging from 100 to 815 × 10⁸/km² in the Anda and Xuzhong areas (Fig. 9). The measured porosity of 9 shale samples is 1.2% ~ 5.3%, and the buried depth is 3000 ~ 4500m, which is a favorable exploration area for natural gas and shale gas in the next step [13 ~ 16].

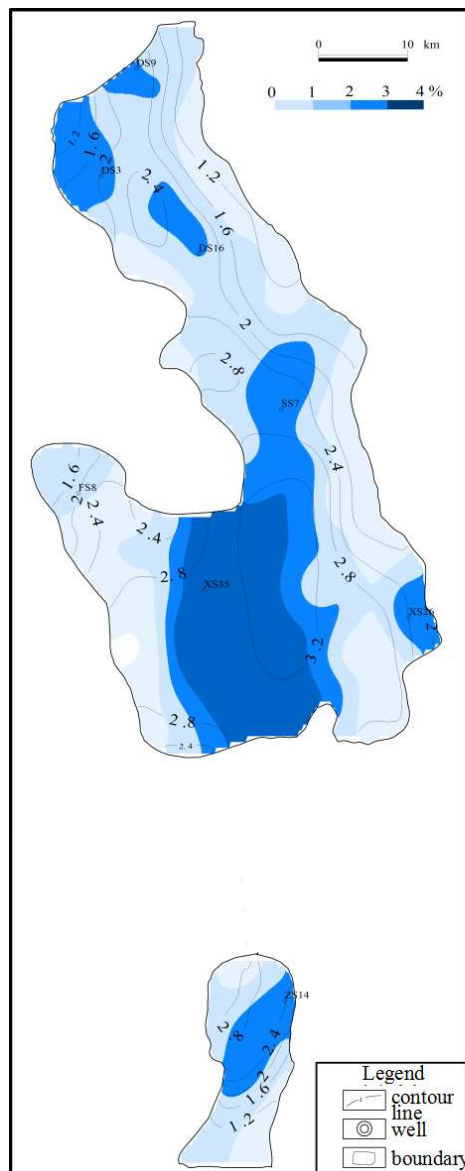


Fig. 9. Superposition of Ro and TOC of mudstone in the fourth member of Shahejie Formation in Xujiaweizi fault depression.

5 Conclusion

- 1) Shahezi Formation develops coal-bearing sedimentary shale dominated by shore-shallow lacustrine facies, with high abundance and over-mature organic matter. It is the main source rock layer in the deep northern Songliao Basin, mainly distributed in the Xujiaweizi fault depression;
- 2) The gas generation of mudstone in Xujiaweizi fault depression is dramatically higher than coal gas generation. The mudstone gas generation volume of the first, second, third and fourth members of the Shahezi Formation is similar, and the mudstone of the fourth member of Shahezi Formation accounts for the largest proportion due to the highest maturity;
- 3) The fourth member of Shahezi Formation in Xujiaweizi fault depression has large mudstone thickness, high abundance and continuous distribution. Anda and Xuzhong, e.g. areas have moderate burial depths, which

are favorable exploration areas for natural gas and shale gas in the next step of the Daqing Oilfield.

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