Fine evaluation of source rocks in Wuergun-Beier sags

Ting Liu

Exploration and Development Research Institute of Daqing Oilfield Co., Ltd.,
Heilongjiang Provincial Key Laboratory of Tight and Shale Oil Accumulation, Daqing,
163712, China

Email: dqlt@petrochina.com.cn

Abstract. Wuergun-Beier sags are two important oil-enriched sags in Hailar Basin, and Nantun Formation is the main layer of source rock. In this study, the Nantun Formation is subdivided into 8 sub-layers. Based on a large number of core observations and thousands of core samples, the quality of source rocks is finely evaluated by combining organic geochemical analysis and logging evaluation method (ΔLogR method), and the lower part of the Nantun Formation is identified as the high-quality source rock distribution layer. The evaluation criteria of high-quality source rocks are established. Based on the fine evaluation of source rocks, the hydrocarbon generation and expulsion potential of source rocks in Wuergun-Beier sags are recalculated, and provides a reliable basis for resource prediction. The fine evaluation system of source rocks established in this study has guiding and referential significance for fine evaluation of source rocks in other sags of Hailar Basin.

1. Research background

With the increasing recognitions of oil and gas exploration and geological conditions, the classification criteria of hydrocarbon source rocks have expanded from "effective source rocks" to "high-quality source rocks"[1,2]. Wuergun-Beier Sags are two secondary tectonic units in Hailar Basin, and Nantun Formation is the main layer of source rock. In this study, the Nantun Formation is subdivided into 8 sub-layers. The Wuergun sag is extended in a north-south direction with an area of 2240Km². The Beier sag is the widest sag in the basin and extended near north-east direction with an area of 3010Km². The two sags are connected by Bayantala structural transition zone[3]. The Cretaceous is the main sedimentary body in Hailar Basin, three sets of source rocks are developed from bottom to top, namely Tongbomiao Formation, Nantun Formation and Damoguaihe Formation. Nantun Formation is the main source rock layer and the major exploration target.

In stratigraphy, the Nantun Formation in Wuergun-Beier sags is subdivided into 8 fourth-order sequences vertically and doing studies towards a more detailed fifth-order sequences. However, the previous research on source rocks is based on intervals and zones, and the degree of research is not fine enough to meet the needs of current exploration, it is urgent to carry out the fine research on source rocks under the framework of subdividing layers, so as to evaluate the resource potential accurately.

2. Fine evaluation of source rocks of Nantun Formation

In this study, a geochemical database of source rocks in Wuergun-Beier sags is established, cores of 129 wells are observed and 2767 samples are collected, the quality of source rocks is comprehensively evaluated by organic geochemical analysis and logging discipline. According to the latest stratigraphic
results of sequence stratigraphy, the Nantun Formation is subdivided into 8 sub-layers, of which K1n1 formation is subdivided into six sub-layers: K1n11, K1n12, K1n13, K1n14, K1n15 and K1n16 (K1n11 is lacked in Wuerxun sag), and K1n2 formation is subdivided into K1n21 and K1n22.

2.1. ΔlogR method for TOC calculation
Owing to the strong heterogeneity of organic matter distribution, which directly affects the continuity and accuracy of fine evaluation of source rocks, the ΔlogR method using logging data for calculating TOC is adopted to obtain continuous high resolution TOC curves [4]. This method eliminates the statistical errors caused by the heterogeneity of organic matter distribution in source rocks, the finiteness of core samples analysis and the randomness of sample acquisition. The calculation result shows that there is a high correlation between calculated TOC values and measured TOC values. 35 core samples of Nantun Formation from Well Bei 39# are intensively sampled. By using ΔlogR method, the correlation coefficient R² between measured TOC value and calculated TOC value is 0.8418, and the curve trend of two values is consistent ‘figure 1’, so the ΔLogR method is suitable for fine characterization and development characteristics of source rocks in Wuerxun-Beier sags. Using the ΔLogR method to establish logging calculation formulas of TOC in Wuerxun-Beier sags, and TOC of 274 wells are calculated, including 132 wells in Beier sag and 142 wells in Wuerxun sag. TOC distribution maps of 8 sub-layers in Nantun Formation of Wuerxun-Beier Sags are completed using the calculation results, and favorable areas for source rocks distribution in two sags are analyzed.

![Figure 1](image_url)

**Figure. 1** The correlation between measured TOC and calculated TOC of samples from well Bei 39#.

2.2. Organic matter abundance of source rocks of Nantun Formation
Under the framework of subdividing layers, a large number of data statistics and histograms of source rock parameters are carried out to reflect the quality of source rocks in study areas directly. Generally speaking, the quality of source rocks of K1n1 formation of is better than that of K1n2 formation in Wuerxun-Beier sags. The average value of TOC, hydrocarbon potential (S1+S2) and hydrogen index (HI) of source rocks of 6 sub-layers of K1n1 formation in Wuerxun sag are 1.80-2.34%, 5.58-8.81mg/g and 241.50-347.29mg/g respectively. Similarly, these parameter values in Beier sag are 1.66-2.30%, 3.34-12.84mg/g, 185.46-482.21mg/g respectively. Comparing the parameters of source rocks in different sub-layers, it is found that the quality of source rocks of K1n13~K1n16, that is the lower part of K1n1 formation in Wuerxun-Beier sags are good, especially the quality of source rocks of K1n15 in Beier sag (table 1).

| Table 1. Statistics of geochemical parameters of Nantun Formation. |
|---|---|---|---|---|
| Formation | Sub-layer | Average value of TOC (%) | Average value of S1+S2 (mg/g) | Average value of HI (mg/g) |
| | | Wuexun | Beier | Wuexun | Beier | Wuexun | Beier |
| K1n2 | K1n21 | 2.58 | 1.78 | 5.37 | 2.99 | 239.77 | 161.14 |
| | K1n22 | 2.31 | 1.81 | 6.04 | 3.32 | 284.56 | 179.17 |
| K1n1 | K1n11 | / | 1.79 | / | 3.34 | / | 185.46 |
2.3. Types and maturity of organic matter in source rocks of Nantun Formation

In the evaluation of organic matter types of source rocks in Wuerxun-Beier sags, four types of kerogen of continental source rocks was used to classify the types II I, II2, II1 and I kerogens. Types of organic matter in Source rocks of K1n1 formation in Wuerxun sag are mainly Type II, while the organic matter types of K1n13~n16 sub-layers source rock are mainly type I. With the increase of TOC, HI distribution increases correspondingly, especially for source rocks with TOC>2%, which indicates that the source rocks in the lower part of K1n1 formation have good organic matter types. The organic matter types of source rocks of K1n2 formation are mainly Type II1, some of them are Type II2, and few of them are Type I and Type III. Therefore, the organic matter types of source rocks of K1n1 formation of Wuerxun sag are better than those of K1n2 formation. The characteristics of organic matter types of Nantun Formation in Beier sag are the same to Wuerxun sag, which still shows that the organic matter types of source rocks in K1n13~n16 sub-layers are good, especially a large amount of type I kerogen has developed in the K1n15 sub-layer.

Through the gas chromatography-mass spectrometry instrument, it was found that the samples from 41 wells in Wuerxun-Beier sags contain β-carotane, and the abundance of gammacerane is very high (figure 2), these samples are concentrated in K1n13-n16 sub-layers. In this study, there is a good correlation between TOC and S2 value of source rock samples containing β-carotane. Previous studies have shown that β-carotane is a fully saturated C40 dicyclane, which mainly exists in algal organic matter in anoxic and saline lake sediments. It is often used to indicate the strong reductive lacustrine sedimentary environment[5,6], which is conducive to the preservation of organic matter. This should be the main reason for the good quality of the source rocks in the lower part of K1n1 formation.

![Figure 2 Mass chromatogram of samples in K1n15 from well Wu 53# (HI: 511mg/g).](image)

Based on the identification of the whole rock macerals, taking the samples of Nantun Formation of well Bei 56# as an example, algae are found in samples of K1n22, K1n12, K1n14 and K1n15 layers (figure 3). The comparison of algae enrichment and fluorescence intensity show that the algae in the samples of lower part of the K1n1 formation are more abundant and the fluorescence is bright yellow, reflecting the better source material. The HI of the K1n15 sample is 680 mg/g, which is much higher than that of other samples, and is consistent with the microscopic observation.

In terms of maturity of source rocks, the maturity distribution of source rocks in K1n1 formation of Wuerxun-Beier sags is larger than that in K1n2 formation. The degree and distribution of maturity of source rocks below the K1n13 increase layer by layer. The distribution range of high Ro in K1n16 sub-layer is the largest, the highest Ro value of Wunan sub-sag in Wuerxun sag can reach 1.96%. Most of the source rocks in Wubei area belongs to matured evolution stage. The maximum Ro value of source rocks in K1n16 layer of Beixi sub-sag in Beier sag is 1.60%, the source rocks in Beizhong sub-sag is fully in matured evolution stage.
Figure. 3 Macerals photographs of source rock samples from Well Bei 56#.

The mature rang of source rocks in \( K_{1n2} \) formation are confined to deep troughs in two sags, such as Wunan sub-sag (\( R_{\text{omax}}=1.56\% \)) and Beixi sub-sag (\( R_{\text{omax}}=1.2\% \)). Therefore, the source rocks in the lower part of \( K_{1n1} \) formation of Wuerxun-Beier sags show high organic matter abundance and good types, and most of the source rocks are in the matured-highly matured evolution stage, which are the main source rock layers of the Nantun Formation in the two sags.

Figure. 4 TOC-\( S_2 \)-HI distribution chart of fine classification of source rocks in the lower part of \( K_{1n1} \) formation in Beier sag.

By studying the correlation between TOC and \( S_2 \), and the HI distribution characteristics of different TOC classifications in the lower part of \( K_{1n1} \) formation in Beier sag ‘figure 4’, it shows that the main types of organic matter in the source rocks of \( K_{1n13-n16} \) sub-layers are type I and type II,
while organic matter type in K1n15 sub-layer is mainly type II partial type I, and Source rocks with TOC>2% have the high HI value. It is considered that the high-quality source rocks in the lower part of the K1n1 formation has characteristics of TOC>2%, S2>15mg/g in Beier sag, and the quality of source rocks of K1n15 sub-layer is best. At the same time, the study concludes that the high-quality source rocks in the lower part of the K1n1 formation has characteristics of TOC>2%, S2>8mg/g in Wuerxun sag.

3. Conclusions and suggestions

Study on subdivision and classification evaluation of source rocks in Wuerxun-Beier sags, a set of fine evaluation system of source rocks classification is established combined geochemical comprehensive analysis, high-quality classification and logging, it is multidisciplinary. For the first time, the organic matter abundance and quality of source rocks are combined, and the variation law of source rock types is confirmed. According to stratification and gradation, the source rocks are finely evaluated and the evaluation criteria for high-quality source rocks are established. It is considered that the high-quality source rocks in the lower part of the K1n1 formation has characteristics of TOC>2%, S2>15mg/g in Beier sag while TOC>2%, S2>8mg/g in Wuerxun sag. The sub-layers of K1n13~K1n16 are identified as the high-quality source rock distribution layers. According to the fine evaluation of source rocks and subdivision layers, the hydrocarbon generation and expulsion potential of source rocks in 13 sub-sags are recalculated, of which 4 sags in Wuerxun sag and 9 sags in Beier sag, this provides a reliable basis for resource prediction. The fine evaluation system of source rocks established in this study has guiding and referential significance for fine evaluation of source rocks in other sags of Hailar Basin.

References

[1] Linye Zhang, Xiangxing Kong, Chunrong Zhang, Wen Zhou, Xingyou Xu and Zheng Li 2003 Hith-quality oil-prone source rocks in Jiyang Depression J. Geochemica Vol. 32(1) pp 35–42
[2] Guangyou Zhu and qiang Jin 2003 Geochemical characteristics of two sets of excellent source rocks in Dongying depression J. Acta Sedimentologica Sinica Vol. 21(3) pp 506–512
[3] Haibo Wu, Yanguang Ren, Junhui Li, He Liu, Hai Deng and Haijun Zhang 2014 Developed characteristics and genetic mechanism of high-quality source rocks in Wuerxun-Beier sags J. Petroleum Geology and Oilfield Development in Daqing Vol. 33(5) pp 154–161.
[4] Chao Liu, Shuangfang Lu, Wenbiao Huang and Weiming Wang 2011 Improvement of ΔlogR and its application in source rocks evaluation J. Petroleum Geology and Oilfield Development in Daqing Vol. 3(3) pp 27–31.
[5] Wei Yin, Herong Zheng, Xianlong Meng and Weifeng You 2005 Geochemical behaviors of crude oils in central Junggar Basin J. OIL&GAS GEOLOGY Vol. 26(4) pp 461–466.
[6] Zhusheng Jiang and Martin G. Fowler 1986 Carotenoid-derived alkanes in oils from northwestern China J. Organic Geochemistry Vol. 10(4-6) pp 831–839