A Method of Favorable Source Rock Evaluation and Prediction: A Case Study From Zhahaquan Oil Field, Qaidam Basin (Nw China)

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Abstract. In recent years, tight oil reservoirs have been found in the upper Ganchaigou Formation (Neogene) of Zhahaquan area, Qaidam Basin, but the source rock–reservoir relationship is unclear and the favorable source rock identification and prediction method need to be built urgently. Based on the experimental data of source rock samples in the study area, it is found that there are a lot of differences between favorable and useless source rocks such as color, degree of redox, salinity, paleo-water depth, carbonate content, TOC, and sedimentary environment. Moreover, after analyzing logging responses of source rock, ΔGR and Th/U are selected to calculate TOC because the two parameters are most sensitive to organic matter abundance. Furthermore, we found that the source rocks in the shallow lake area and beach bars are longitudinally superimposed on each other, and this combination is beneficial to form high-class source rock–reservoir collocation. And, the distribution of source rocks in shallow lake area is basically parallel to the lake shoreline and is consistent with the strike of beach bars. This method can be applied to favorable source rock identification and prediction of different types of areas.

Keywords: Tight oil · Source rock · Logging · Qaidam Basin

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1 Introduction

In recent years, a breakthrough has been made in the upper Ganchaigou Formation of Zhahaquan area, Qaidam Basin, and millions of tons of tight oil reserves have been found [1, 2]. Geological analysis suggests that Zhahaquan area is an alternative sedimentary environment of shore shallow and semi-deep lacustrine. Longitudinally, the source rock is interbedded with non-source rock mudstone and reservoir rock. Therefore, identifying and predicting favorable source rock is a key technical problem in finding tight oil targets.

The typical high-quality source rocks have logging characteristics of the high neutron, high acoustic time, high resistivity, high natural gamma ray, and low density. Based on these characteristics, many scholars have proposed some methods to identify source rocks [3–7]. And recently, because of advances in logging techniques, some new methods were presented to evaluate source rocks more accurately [8–10]. However, in study area, the effect of traditional methods for evaluating source rock is poor. And because of the high cost of advanced logging tools such as NMR logging tool and geochemical logging, some related technologies are difficult to popularize.

First, in this paper, elemental geochemical characteristics of core samples are summarized, and then, the evolution law of sedimentary environment and the changing law of organic matter abundance are clarified, so that the differences between favorable and useless source rocks are clear. Second, the two parameters, ΔGR (difference between total gamma ray and gamma ray without uranium) and Th/U, are, respectively, used to find the relation between organic matter abundance and sedimentary environment. Furthermore, we used the two parameters to calculate total organic content (TOC), and the result is good. Finally, by means of evaluation of source rocks, the distribution range of favorable source rocks is clear. This work can support the study of source–reservoir relation and sedimentary facies classification.

2 Geological Background

The Zhahaquan Formation is a nose-like anticline, located in the southwestern Qaidam Basin (Fig. 1). The upper Ganchaigou of late Tertiary is the oil-bearing series, while can be divided into six layers, layer 1, 2, 3, 4, 5, and 6. Layer 4, 5, and 6 are potential tight oil layers, and the other three layers are a conventional resource [11]. The main lithology of these tight oil layers is siltstone with an average mineralogical composition of 40% quartz, 20% feldspar, 20% carbonate, and 20% clay. The TOC and Ro ranges are 0.6–2.5% and 0.6–1.0%, respectively.

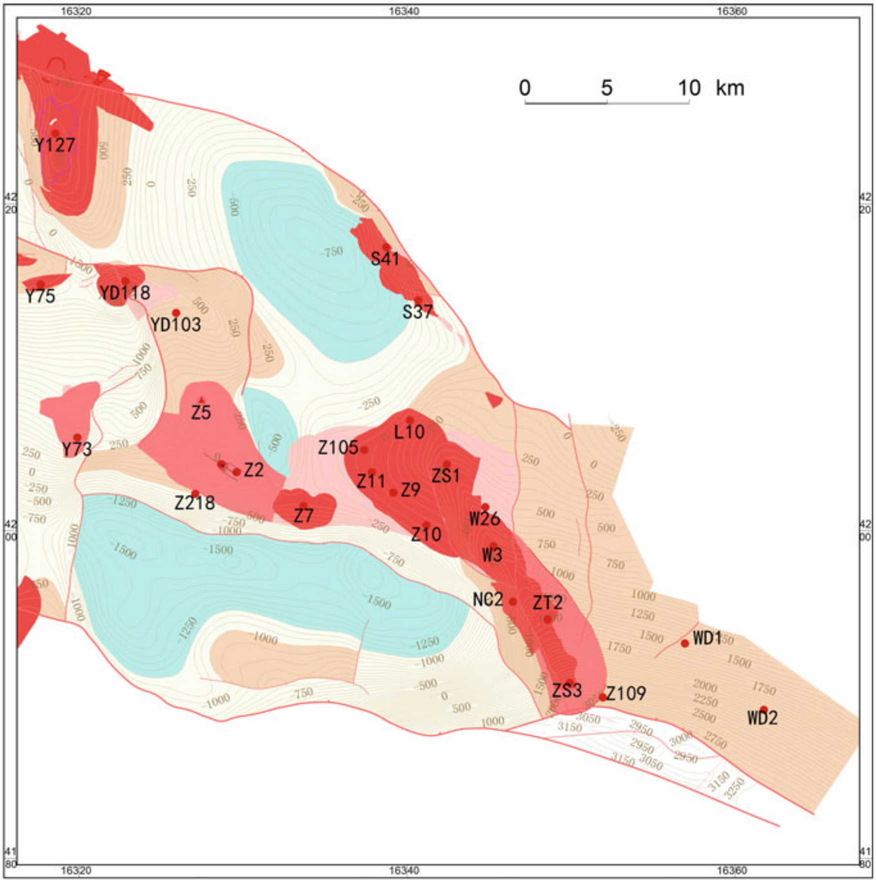

Fig. 1. Structural contour map of Zhahaquan area with well locations [11]

3 Source Rock Characteristics

The experimental analysis suggests that there are certain variation laws existing in the carbonate content and organic matter abundance of different types of source rocks (Fig. 2). The carbonate content of oxide-colored mudstone is 15–25%, which is called limy mudstone; the carbonate content of dark mudstone is 25–75%, which is called lime mudstone or argillaceous limestone. With the carbonate content increasing, the sedimentary environment transits from shore shallow lacustrine to semi-deep or deep lacustrine. For the dark mudstone, with carbonate content increasing, TOC shows a parabolic change which increases first and then decreases.

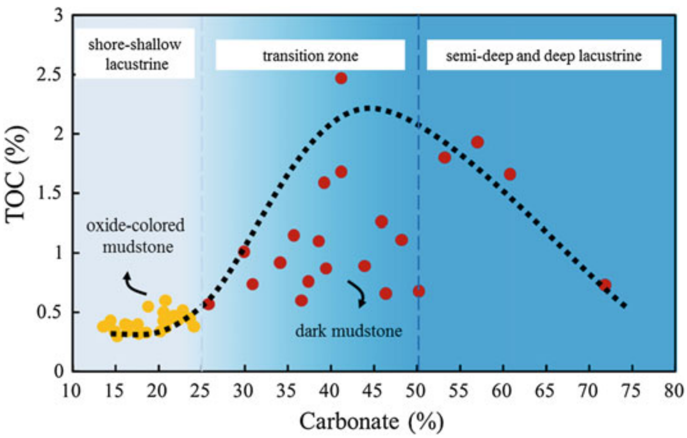

Fig. 2. Variation law of TOC

By thin section observation, it has been found that carbonate laminae are developed in high-abundance source rocks. Also from the SEM images and energy spectrum distributions, carbonate laminae dominated by calcite and dolomite are developed in clay-size debris and clay minerals (Fig. 3).

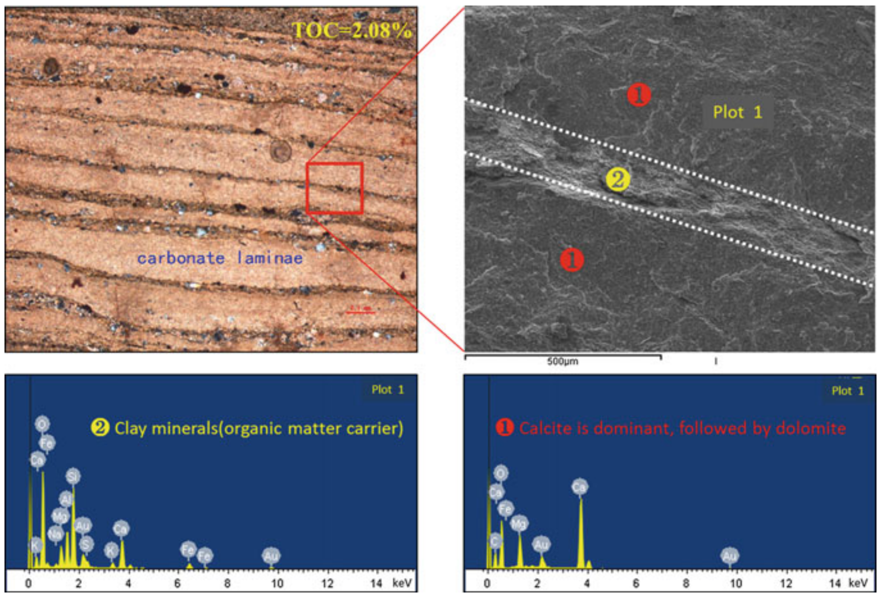

Fig. 3. Microstructure and mineral composition of favorable source rock

In addition, according to the carbon and oxygen isotope data and its covariation relationship with carbonate content and elements (Fe^{2+}/Fe^{3+}, Th/U), it is clear that the high salinity area of the lacustrine basin represents the deepwater sedimentary environment, and the low salinity represents shallow water sedimentary environment. Dark mudstones are deposited under higher salinity and deeper reducing environment; oxide-colored mudstones are deposited under less salinity and shallow weak-oxidizing environment (Fig. 4).

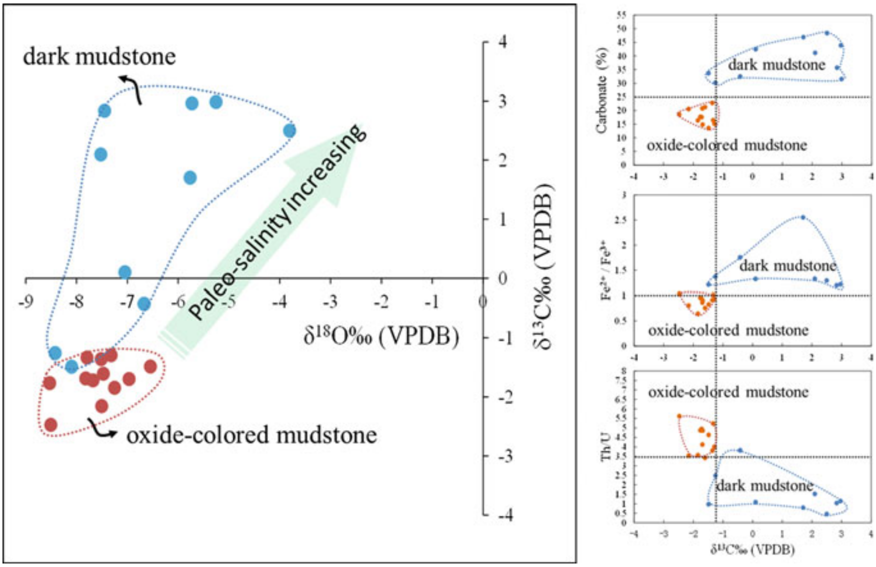

Fig. 4. Analysis diagram of geochemical elements

Based on the experimental data of source rock samples in the study area, we know that dark mudstone is favorable source rock. And it is found that there are a lot of differences between favorable and useless source rocks such as color, degree of redox, salinity, paleo-water depth, carbonate content, TOC and sedimentary environment, and accord to this we can determine that if the source rock is effective.

4 Source Rock Logging Evaluation

Logging data, which is continuous in longitudinal direction, can be used to evaluate the organic matter abundance of source rocks. We calibrate logging data via core data, select sensitive parameters based on logging response, and evaluate source rocks of a single well.

5 Source Rock Logging Responses

Compared with non-source mudstones, high-quality source rocks have logging characteristics of the high neutron, high acoustic time, high resistivity, high natural gamma ray, and low density. But in the study area, source rocks do not have these characteristics, and the correlation between TOC and parameters such as AC, GR, Rd, and DEN is poor (Fig. 5).

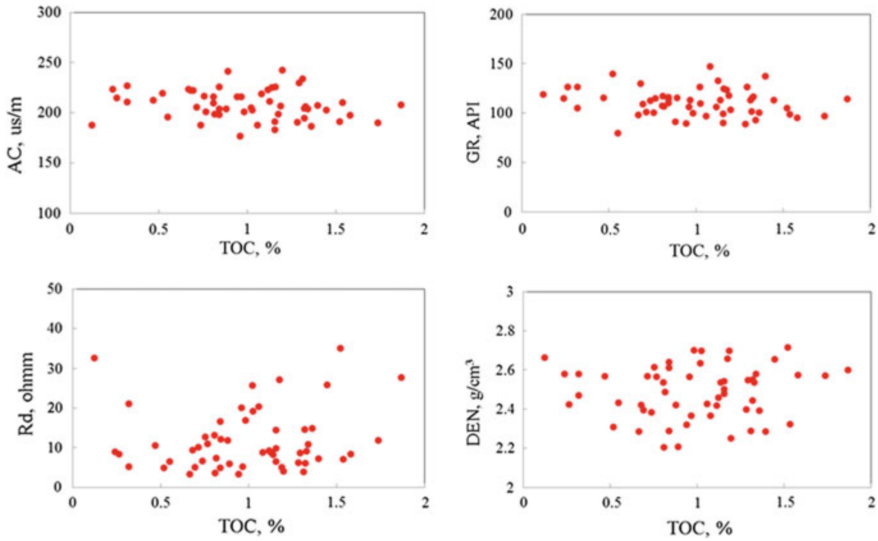

Fig. 5. Crossplots of TOC and logging parameters

6 TOC Calculation Method

Compared with logging parameters, it is found that the correlation between Th/U and TOC is better, so does ΔGR and TOC (Fig. 6). Specifically, Th/U is negatively correlated with TOC, and ΔGR is positively correlated with TOC, which is related to the fact that organic matter is easier to adsorbed uranium. The higher the TOC is, the more uranium can be adsorbed; and the lower the Th/U is, the greater the difference between total gamma ray and gamma ray without uranium is. Therefore, the two parameters, Th/U and ΔGR, are used to quantitatively calculate TOC.

We built Eq. (1) to calculate TOC of the study area. Coefficients A, B, and C are selected according to the area conditions. For Zhahaquan area, A, B, and C take values of 0.019, −0.030, and 0.037, respectively. Comparing TOC results from core samples and logs, the correlation between them is good (Fig. 7).

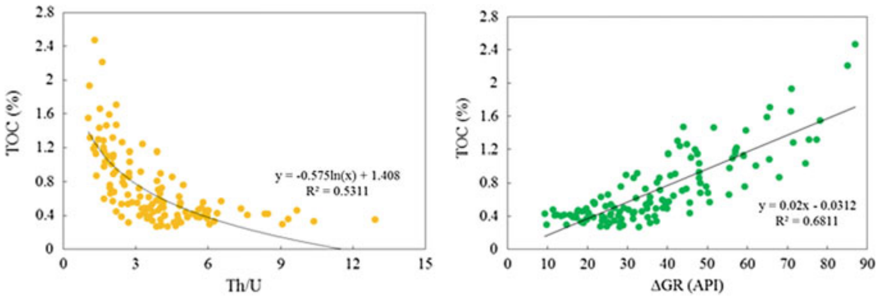

Fig. 6. Crossplots of TOC and Th/U, ΔGR

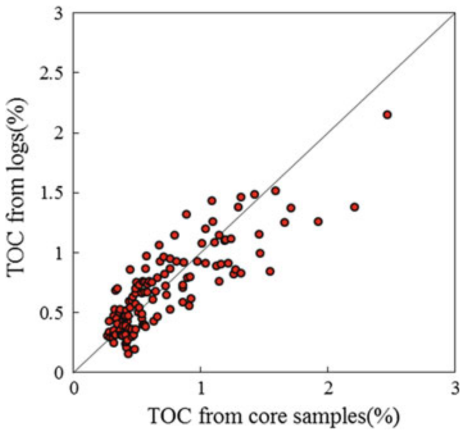

Fig. 7. Comparison plot of TOC from core samples and calculated by logs

$$\mathrm{TOC} = A \times \Delta\mathrm{GR} + B \times \ln(\mathrm{Th}/\mathrm{U}) + C \tag{1}$$

7 Favorable Source Rock Prediction

We identify favorable source rocks of 24 wells in the study area, calculate the thickness of favorable source rocks in each layer, and acquire their distribution range and trend (Fig. 8). First, after overlaying source rock thickness contours and sedimentary facies maps, it is found that the source rocks in the shallow lake area and beach bars are longitudinally superimposed on each other, and this combination is beneficial to form high-class source rock–reservoir collocation. Second, the distribution of source rocks in the shallow lake area is basically parallel to the lake shoreline and is consistent with the strike of beach bars. At last, in terms of the distribution of favorable source rock from layer 4 to 1, its development zone gradually migrates from northwest to southeast.

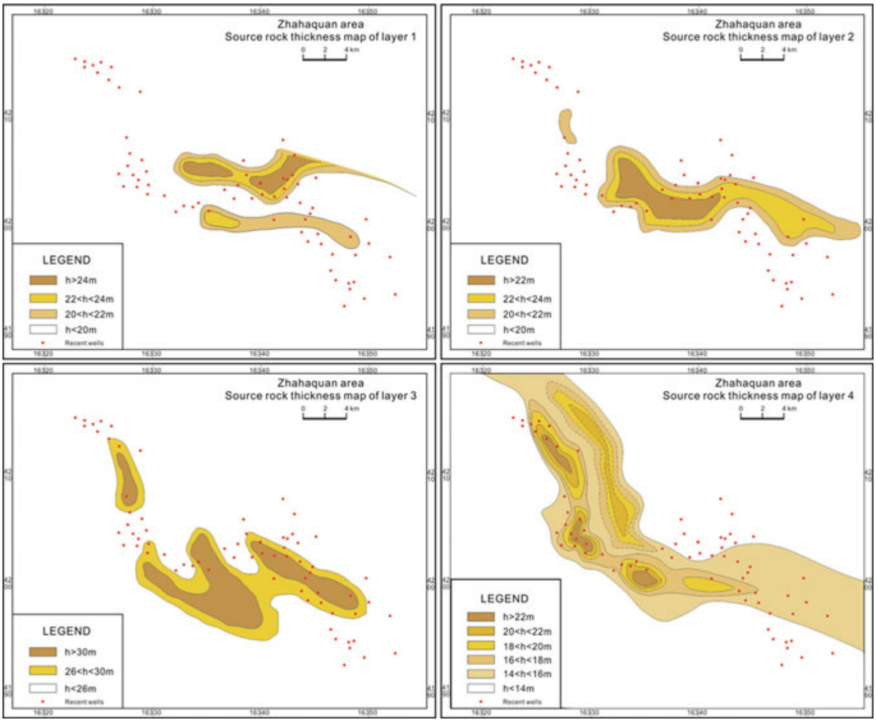

Fig. 8. Source rock thickness maps of layer 1 to 4

8 Conclusion

This paper starts with the geological characteristics of source rocks, and we summarize the geochemical indicators of favorable source rocks through various experimental methods. Then, the source rocks of a single well are evaluated by logging data, and finally, the distribution range and trend of favorable source rocks in each group are obtained. This method can support finding tight oil targets and is endorsed by oil companies.

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