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Research Advances

Enrichment Patterns and New Discovery of Deep Lacustrine Shale Oil in the Upper Cretaceous Qingshankou Formation, Songliao Basin, NE China

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Objective

The Songliao Basin is located in northeastern China. The Upper Cretaceous Qingshankou Formation (Fm.) (K_2qn), Yaojia Fm. (K_2y), and Nenjiang Fm. (K_2n) were deposited in its depression. The sediments are mainly continental clastic rocks. The first member of the Qingshankou Fm. (K_2qn_1) in the southern Songliao Basin mainly comprises semi-deep to deep lacustrine shale of large thickness, generally 30,100 m, with wide distribution; the thickness of the shale has an average thickness of 70 m. Moreover, organic matter abundance is high and the maturity moderate. This shale is the main oil-bearing layer and caprock in the Songliao Basin, which, at the same time, forms a realistic oil and gas replacement area with a high content of retained hydrocarbons and abundant pure shale oil resources. The semi-deep–deep lacustrine shale oil is the most difficult type to explore and develop in China because of its high clay mineral content and extremely low permeability and so is the object of our study.

Methods

Core observation, thin-slice identification, geochemical logging, elemental logging, X-ray diffraction analysis, organic-inorganic geochemical analysis, microscope analysis were all used to study the organic-inorganic geochemical characteristics, style of paleoenvironment, favorable lithofacies types and effective reservoir characteristics of the deep lacustrine shale in the first member of the Qingshankou Fm. Scanning electron microscopy, fluorescent thin film and nitrogen adsorption were used to study the microscopic characteristics, fluorescence characteristics, pore type and pore throat structure. C_6H_{14} and CH_2C_{l2} were used to separate the light and heavy hydrocarbon components in shale samples step by step, combined with nitrogen adsorption to obtain the mass and volume proportions of the flowable light hydrocarbon components in different lithofacies. Then, a deep lacustrine shale oil enrichment model was established to guide the deployment of well positions for the JHF1HF well and optimization of dessert layers. Finally, an oil source comparison was performed through biomarker analysis to verify the effectiveness of the enrichment model.

Results

Analysis of shale mineral composition, organic geochemical parameters, and major elements of the Qingshankou Fm. first member found that there was an clear lithology–geochemical interface forming two independent shale oil systems. Our research shows that the shale can be classified into two lithofacies. The upper layer shale develops horizontal bedding, its average content of clay minerals is 64%, the content of autogenous pyrite is high and the content of TOC is 3%～5%, with the organic matter mainly of type I composed of endogenous layered algae. The trace element parameters indicate that the upper layer shale was formed in a deep-water humid strong-reducing paleoenvironment and that its lithofacies type is high-TOC microstratification argillaceous shale. The lower layer shale develops sandy strata, its average content of clay minerals is 38%, the content of autogenous pyrite is high and the content of TOC is 2%～3.5%, with the organic matter mainly of types I and II_1 composed of endogenous layered algae. The paleoenvironment of the lower layer shale was a semi-deepwater, damp and reducing and its lithofacies type is moderate-high-TOC-laminated diamictic shale.

The results of our study of microscopic and fluorescence characteristics, pore type and pore throat structure and separation of the light and heavy hydrocarbon components in the first member shale, combined the mass and volume proportions of the flowable light hydrocarbon components in the different lithofacies show that the upper layer shale had the highest total oil content with an average S_1 of 5 mg/g. The content of free light components was relatively high within the total oil content and the proportion of mobile oil can reach 45%. The upper layer shale mainly develops bedding fractures and micro-fractures, with an average porosity of 6.2%; fluorescence showed that the effective storage spaces of the shale oil were mainly these fractures and micro-fractures; The lower layer shale had the higher total oil content with an average S_1 of 3 mg/g. The content of free light components was relatively high and the

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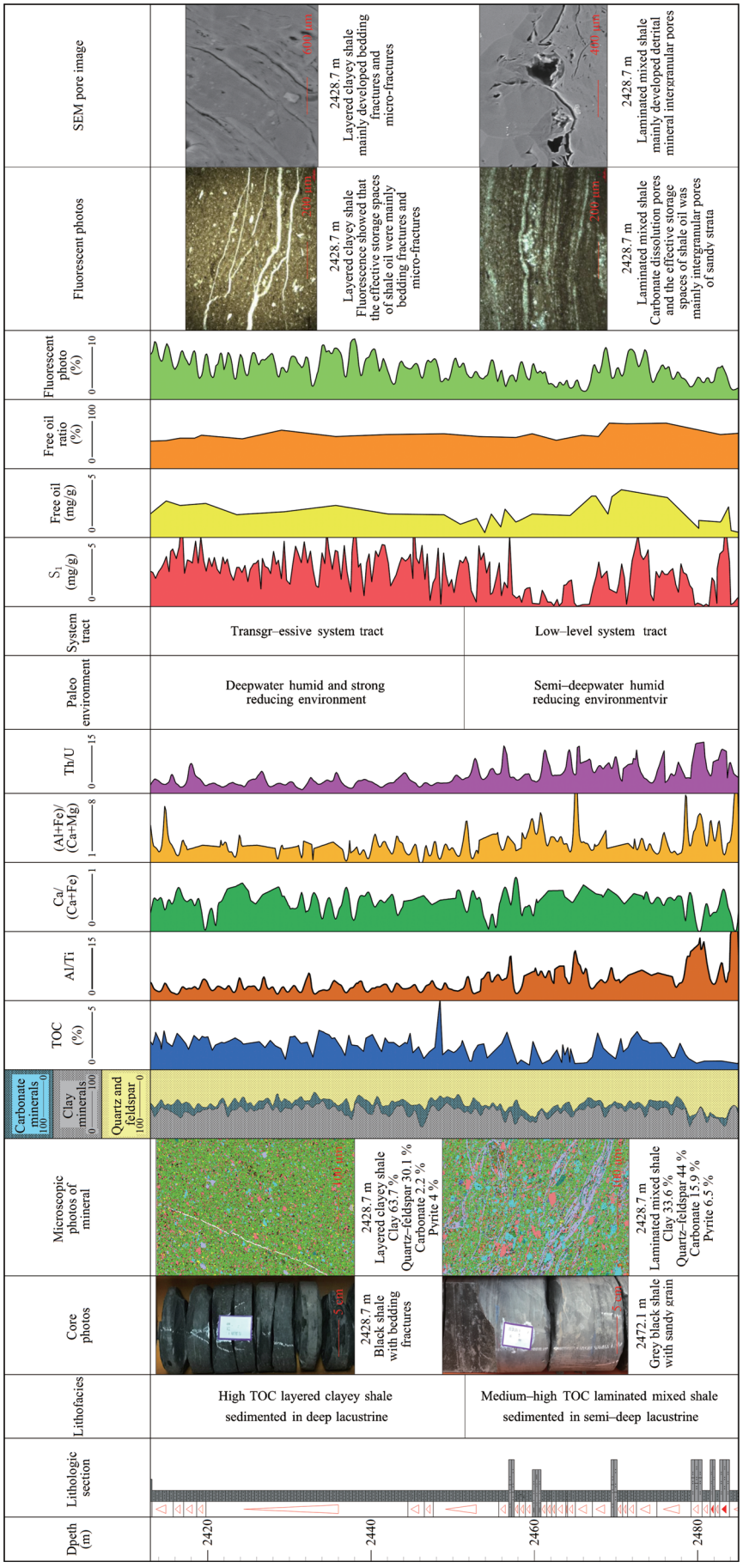

Fig. 1. Enrichment patterns of shale oil in the Upper Cretaceous Qingshankou Formation, Songliao Basin, NE China.

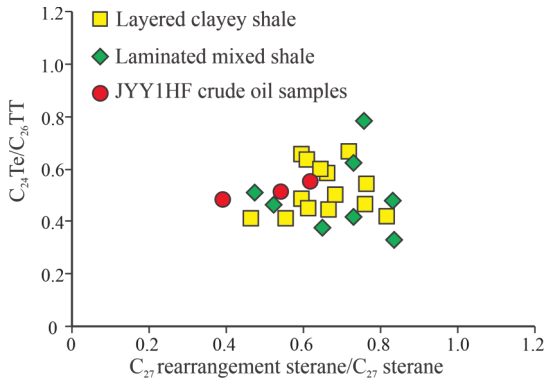

Fig. 2. Comparison of the biomarker characteristics between the crude oil of JYY-1HF well and each formation of the Qingshankou (K_2qn_1) Fm.

proportion of mobile oil can reach 53%. The lower layer shale mainly develops detrital mineral intergranular pores, the average porosity of which is 4.5%. Carbonate dissolution pores and the effective storage spaces of the shale oil was mainly intergranular pores of sandy strata (Fig. 1).

Conclusions

According to comprehensive research and our enrichment model, two types of shale with deep-water high-TOC microstratification shale and semi-deepwater moderate to high TOC-laminated shale provide favorable lithofacies for shale oil enrichment. Based on the above understanding, the JYY1HF well was deployed and implemented in the southern Songliao Basin. The well has obtained high-yield industrial oil flow with 16.4 m^3 per day and maximum daily oil production of 36 m^3. Crude oil analysis results show that C_{27} rearrangement sterane/C_{27} sterane, $C_{24}Te/C_{26}TT$ and other biomarker parameters of the oil from the JYY1HF well are consistent with the upper and lower layer shale (Fig. 2). Therefore, the effectiveness of the two enrichment patterns of the shale oil were confirmed. In addition, we carried out a fluid production profile test and flowback fluid trace analysis of well JYY1HF. The results show that the shale oil production of this well is mainly contributed by the laminar shale, with a contribution rate of 63%, and the contribution rate of the microstratification shale is 37%. The two enrichment models established in this study effectively guided the JYY1HF well to obtain industrial shale oil in deep lacustrine shale and thus open up a new exploration field for continental shale oil in China.

Acknowledgements

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