LACUSTRINE SHALE CHARACTERIZATION AND ITS IMPLICATION IN IDENTIFYING SWEET SPOTS IN THE QIJIA-GULONG DEPRESSION, SONGLIAO BASIN

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The Songliao Basin has experienced twice transgressions in the Late Cretaceous, which formed two sets of excellent source rocks widely present in the basin, i.e. the Qingshankou formation and the first two members of the Nenjiang formation. The source rock of Qingshankou formation is thermally mature in the Qijia-Gulong depression, which sourced most of conventional resources of mid-shallow formations in the Songliao Basin, while oil content retained by the source rock is thought to be an important unconventional resources. Previous exploration activity has seen many economic wells with oil produced from the shale in the Qijia-Gulong depression, indicating that they may provide abundant oil resources in this area. The evaluation of shale and identification of sweet spots will support the exploration of shale oil in this area.

1. Geochemical characteristics of shale

In the Gulong depression, the dark mudstone thickness of the Qingshankou 1st member (K_2qn^1) ranges 60-80m, while in the Qijia depression, the thickness ranges 50-80m. The mudstone thickness of the Qingshankou 2nd member (K_2qn^2) is generally larger than that of the K_2qn^1. The mudstone thickness of the K_2qn^2 in the Gulong depression is in the range of 180-230m, while in the Qijia depression the thickness is in the range of 50-150m. Therefore, the Gulong depression has thicker mudstone than the Qijia depression.

The shale in the K_2qn^1 of the Qijia-Gulong depression is rich in organic content and the average TOC content is 2.3%, while the K_2qn^2 has an average TOC content of 1.73%. The vertical TOC profile of the Qingshankou formation shows that the TOC content is highly heterogeneous, especially in the K_2qn^2. The TOC content decreases from the bottom of the K_2qn^2 with the average TOC content in the lower part at 2.1%, while the upper part has an average TOC content of 1.1%.(Figure.1). The TOC content in the K_2qn^1 is relatively homogeneous. Spatially, the TOC content of the shale in the K_2qn^1 varies a little. In the Qijia-Gulong depression the TOC content ranges 1.8-2.5% with the Gulong depression having higher TOC content. Organic petrology analysis shows that the K_2qn^1 shale is dominated by type I kerogen the oil precursor is mainly lamellar algae. The source rock maturity of K_2qn^1 in the Qijia depression ranges 0.7-1.1%Ro, while in the Gulong depression the range is between 0.8-1.4%Ro, indicating that the source rock is in the peak to late oil generation stage, which is preferred by the exploration and development of shale oil.

The oil content and oil saturation index (S_1/TOC, TI) are important parameters to evaluate shale oil. The geochemical analysis of the K_2qn^1 shale in the Qijia-Gulong depression shows that in the Gulong depression, the S1 content ranges 0.2-5.94mg/g with an average of 1.94mg/g and the chloroform extract (bitumen "A") ranges 0.061-1.67% with an average of 0.6%. In contrast, the K_2qn^2 shale has lower oil content than K_2qn^1. The TI value of K_2qn^1 shale in the Gulong depression ranges 50-130mg/g TOC while in the Qijia depression, the value ranges 20-80mg/g TOC. Based on S_1 content and TI value maps, there are 6 shale oil sweet spots, mainly located in the Gulong depression.

2. Mineral composition of shale

The bulk XRD analysis of the K_2qn^1 shale shows that the shale is mainly composed of quartz, feldspar and clay with little content of carbonate. The average content of quartz is 36%, and the clay is 36%, the feldspar is 18% and the carbonate is 7.3% with little content of pyrite. With

the increase content of siltstone in the shale, the content of feldspar and carbonate increases with the decrease of both clay and quartz content. Spatially, the Gulong depression has higher content of quartz plus carbonate than the Qijia depression. There are multiple thin layers of sand and ostracod fossil, which increase the brittleness of the K_2qn^1 shale. Generally, the shale in the Gulong depression has more layers of sand and ostracod.

3. Shale reservoir characteristics

The bulk porosity of mature shale has porosity in the range of 4-10%, indicating that shale has a certain amount of storage. The micro-pore structure in the shale was studied using technologies such as SEM and mercury injection. The result shows that pores in the K_2qn^1 shale can be identified as inter-crystal pores, organic pores, dissolution pores, inter-granular pores and micro- to nano-scale fractures. The inter-crystal pores are the most common pore type in the K_2qn^1 shale and pore diameter between illite sheets mainly ranges 1.0-3.5μm. Organic pores were the result of shrinkage of algae due to hydrocarbon generation, and increase with organic maturity. The pore radius of the shale mainly ranges 10-16nm, and the large pores generally have the radius of 30-40nm with some larger than 100nm.

4. Sweet spot identification

The sweet spots were defined by proved wells producing shale oil, in combination with shale thickness, TOC, Ro, S_1, oil saturation index(OSI), GOR(gas oil ratio), quartz plus carbonate content, thin sand interlayer distribution and ostracod fossil presence, formation pressure, and etc. The result shows that the preferred shale oil target is in the Gulong depression, in which the Bayanchagan area is the most promising sweet spot, where TOC>2.0%, Ro>1.0%, S_1>2.5%, TI>100 mg/g TOC, quartz+carbonate >42%, and there are multiple thin sand interlayers and ostracod fossil, and gas content also show some anomalous.

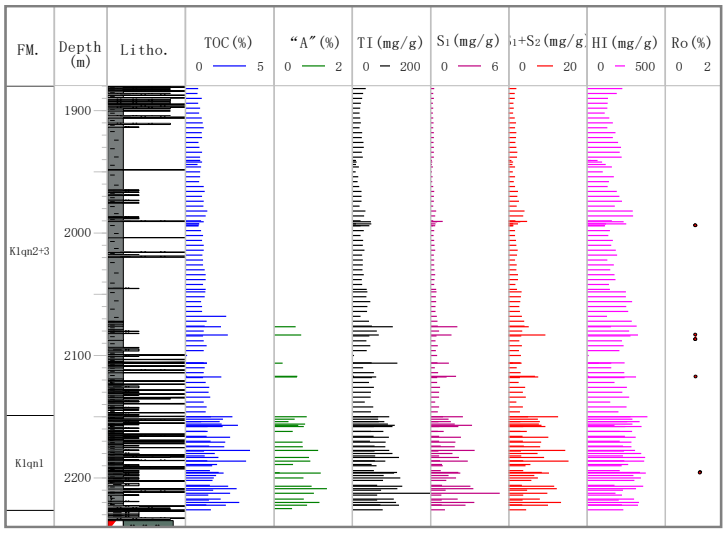

Figure 1 *Geochemical variations in the Qijia-Gulong depression of the Songliao Basin.*

References

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