Analysis of Formation Conditions of Shale Oils in the Changling Depression, Southern Songliao Basin

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1 Introduction

Previous research has reported that organic-rich shale is hydrocarbon source rock or good hydrocarbon sealing barrier, while it is not oil and gas reservoir. Therefore, it has not gained attention in the oil and gas exploration and development. However, with the discovery of rich oils in shale, shale has been proven to be a good resource of shale oils. So far, oil industries in the world are turning their attention from the conventional oil and gas to the unconventional oil and gas, such as tight oil (gas) and shale oil (gas). Shale oil and gas has become the hotspot of oil and gas exploration and development, which is expected to be important oil and gas fields in the next 20 to 30 years.

Songliao Basin, which is one of the largest continental petroliferous basins in China, is rich in oil and gas resources. Changling Depression is located in the south of the central depression of the Songliao Basin. It covers an area of more than 20,000 km², with a basal maximum depth of about 9000 m. There were several tectonic episodes during the depression period in the Changling Depression. In the late period of the Nenjiang Formation, tectonic movement is the strongest, which affected by fold uplift in southeast uplift area. While the strong pressure torsion movement in the late period of the MingShui Formation contributes to the formation of central depression area and west slope area. After depression period, the study area was influenced slightly by the tectonic movement in the late period of the Nenjiang Formation. Structures are simple and stable, and they belong to large depression. Moreover, faults, which develop not very well, can be divided into the Daqingzi low uplift, Qianan sub-concave, Heidimiao sub-concave, west slope, southern slope and eastern slope, etc.

2 Forming Conditions of Shale Oil

2.1 Characteristics of hydrocarbon-bearing mudstone

Influenced by the basal ancient tectonic background and depositional hydrodynamic conditions, lake basin in the southern Songliao Basin (Nen 1 Member of the Negjiang Formation to Ming 2 Member of the Mingshuitai Formation) is generally shrinking. From bottom to up, the sedimentary facies change from half-deep lake and deep lake subfacies to shallow lake subfacies to delta front subfacies (braided river delta front subfacies) to delta plain subfacies (braided river delta plain subfacies). Qingshankou and Nenjiang Formations formed in the twice prosperous period of lake expansion. And two sets of half-deep lake and deep lake facies dark mudstones widely deposited in this period, which provides an important material basis for the formation of shale oil.

2.2 Geochemical characteristics of oil-bearing mudstone

2.2.1 Abundance of organic matter

Total organic carbon (TOC) contents of most mud shales in the Nen 1 member of Yaonan 5 well are generally higher than 2.0%, with an average of 2.99%. The bitumen “A” contents have a mean of 0.49%. It indicates that they are good hydrocarbon source rocks. The TOC values of mud shales in the Nen 2 member range from 1.0% to 4.0% with an average of 2.51%; the average of their bitumen “A” contents is 0.29%, which also shows that these mud shales are good hydrocarbon source rocks.

In general, the high TOC and bitumen “A” contents of mud shales in the Nen 1 and Nen 2 members mainly distribute in the Yaoyingtai-Dahl Khan region.

2.2.2 Type of organic matter

According to the rock pyrolysis analysis, the kerogen type of hydrocarbon source rocks in the Nen 1 member is

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given priority to with type II and type I. However, hydrocarbon source rocks in the Nen 2 member are dominated by type II and type II with less type I. It provides the favorable condition for the formation of shale oil.

2.2.3 Thermal evolution of organic matter

The vitrinite reflectance (Ro) values of mud shales in the Nen 1 member of Yaonan 5 well range from 0.75% to 0.8%, reaching to low mature-mature evolutionary stages. High Ro values mainly distribute in the southwest of Yaoyingtai region. The Ro values of the Suotu and Yaoyingtao regions are in a range of 0.6-0.7%. In addition, Ro values of mud shales in the Nen 2 member are between 0.6% and 0.7% (low mature stage), with high values distributed in between the Suotu and Yaoyingtai regions. Hydrocarbon source rocks in both Suotu and Yaoyingtai - Dongling regions have stepped into the hydrogen generation threshold.

The mature threshold of source rocks in the Qingshankou and Nenjiang Formations occur at approximately 1500 m.

2.3 Show of oil and gas and their geochemical characteristics

Dark mudstones and thin-layer sandstones in most wells (Qingshankou and Nenjiang Formations) of Suotu and Yaoyingtai regions were found in high hydrocarbon shows during the process of oil and gas exploration. For example, gas measurement value in the black mud shales section of the Nen 1 member of Yaonan 5 well is approximately 3.5%, which displays that there is a good exploration prospect of shale oil in the study area.

Continuous extraction and analysis of hydrocarbon-bearing mud shales in the study area were carried out in order to study their oil content, occurrence of hydrocarbon and geochemical characteristics. The results show that crude oils in Nenjiang Formation are characterized by high content of high carbon number n-alkanes. The \( \frac{\Sigma C_{21}}{\Sigma C_{22}} \) and \( \frac{C_{24}}{C_{26}} \) ratios are between 0.43 and 0.57. Concentrations of C24 tetracyclic terpane are relatively high, and C24 tetracyclic terpane /C26 tricyclic terpane ratios range from 1.13 to 2.17. However, abundances of long chain tricyclic terpane, gammacerane and diasterane are relatively low. The (C19 - C29) tricyclic terpane /C26 hopane, gammacerane /C30 hopane and diasterane/regular sterane ratios are less than 0.24, 0.15 and 0.06, respectively. By contrast, \( \frac{\Sigma C_{21}}{\Sigma C_{22}} \) and \( \frac{C_{24}}{C_{26}} \) values of crude oils in the Qingshankou Formation are in the range of 1.35 to 3.25. The C24 tetracyclic terpane /C26 tricyclic terpane ratios are less than 0.74. The (C19 - C29) tetracyclic terpane /C30 hopane are generally higher than 1.0 with a maximum of 5.16. The gammacerane /C30 hopane values are higher than 0.2, and maximum is 0.64. The diasterane/regular sterane values are between 0.26 and 0.50.

From what has been discussed above, it can be found that crude oils in the Nen 2 and Nen 4 members show similarity to mud shales in the bottom of Nen 1 and Nen 2 members, and obviously differentiate with mud shales in the middle-upper of Nen 2 and Qin 1 members. Therefore, crude oils of the Nenjiang Formation can be inferred to derive from the bottom mud shales of the Nen 1 and Nen 2 members.

2.4 Reservoir space characteristics of oil-bearing mudstone

Shale oil belongs to the authigenic storage type of oil and gas reservoir. Mud shale has certain reservoir space, while there is obvious difference between their reservoir space characteristics and the conventional oil and gas reservoir. The reservoir of mud shale is characterized by low porosity and low permeability, nano-sized porosity and well-developed micro-cracks.

The results show that the porosity is relatively high with an average of 9.52%; the permeability is relatively low with an average of 0.000768 md in the Nen 2 member of Yaonan 5 well. However, the mean of porosity and the permeability in the Nen 1 member of Yaonan 5 well is 0.38% and 0.00332md, respectively.

By the analysis of the scanning electron microscopy, it is discovered that medium micro-cracks of mud shales in the Nen 1 and Nen 2 members develop well. They mainly include four kinds of micro-cracks, namely, interlayer micro pore, organic matter micro pore, bioclastic micro pore and intergranular micro pore. The interlayer micro pore and bioclastic micro pore are the main types of micro pore. Moreover, connectivity of these reservoir spaces is relatively good.

Rock mercury injection technology was used to determine the pore throat of mud shales in the Nenjiang Formation of Yaonan 5 well. The pore throat is proven to be fine slanting, fine throat and poor sorting. In general, it belongs to low porosity-ultralow porosity and low permeability reservoir.

2.5 Compressibility of oil-bearing mudstone

Compressibility is one of the most important factors in the reservoir evaluation of shale, which plays a vital role in the fracture-making ability of hydraulic fracturing in mud shale. However, compressibility mainly depends on mineral composition and other factors.

The analysis of X-ray diffraction confirmed that dark mudstone in the Nenjiang Formation is composed of clay minerals, quartzs, potash feldspars, plagioclases, calcites, dolomites, pyrites and siderites. The content of clay
minerals is between 30% and 50%, in which brittleness mineral contents range from 30% to 65%. The content of clay minerals in the Nen 2 member is lower than that in the Nen 1 member, while the content of quartzs in the Nen 2 member is higher than that in the Nen 1 member.

Comprehensive evaluation of the shale brittleness, quartz content, natural fracture illustrated that mud shales in the Nenjiang Formation are characterized by medium fracture property, which is obvious lower than the Yuye 1 well (0.4855) and Barnett shale (0.4844).

Through systematical analyses of thickness, organic matter abundance, maturity, oil content, compressibility and other characteristics of the hydrocarbon-bearing mud shales in the Nenjiang Formation, the favorable exploration areas of shale oil were inferred. The favorable exploration areas of the Nen 1 member mainly focus on the western of Yaoyingtai-Yaonan region and the east of Suotu region, while favorable exploration areas of the Nen 2 member distributed in the midwest of Yaoyingtai region and the eastern of Suotu region. In whole, the spread area of the Nen 2 member is smaller than that in the Nen 1 member.

3 Conclusions

Mud shales in the Nen 1 and Nen 2 members of Changling Depression in southern Songliao Basin are characterized by large thickness, wide distribution, and high abundance of organic matter, moderate thermal evolution degree, general reservoir physical property, medium fracturing and good oil-bearing property, which illustrates that it provides favorable conditions for the formation of shale oil.

References