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Controlling Function of Overlying High-Quality Source Rock on Above-Generation and Below-Storage Tight Oil Reservoirs

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In the process of oil and gas accumulation about continent faulted lake basin of China, the theory that"high-quality source rocks controls hydrocarbon accumulation"has been accepted by many scholars at home and abroad (Jin et al., 2008; Lu et al., 2012). Especially, the formation of tight oil reservoirs must be rely on high-quality source rocks. For instance, Bakken formation in north America develops two sets of high-quality source rocks, which have large thickness, wide distribution, high abundance, excellent types and high hydrocarbon potential and other features (Webster, 1984). What's more, the formation of tight oil in Yanchang group of Ordos basin and Lower Ganchaigou formation of Qaidm Basin in China are all based on the widely distributed high-quality source rocks (Bai et al., 2013; Fu et al., 2013). But, there is no unified understanding at what's high-quality source rocks so far. For example, Wang Li (2009) think source rocks whose TOC＞1.0% is high-quality source rocks (Wang et al., 2009). However, Zheng Hongju (2007) and Lu Shuangfang (2012) pointed out that TOC=2.0% is the minimum of high-quality source rocks. In comparison to this, Hou Dujie (2008) hold that its TOC lower limit must greater than 3.0%. And more importantly, the above mentioned evaluation standards are built rely on experience and lack scientific evidence. Aimed at the weak link, this paper establishes the evaluation standard of high-quality source rocks in abundance and maturity of organic matter through the point of hydrocarbon expulsion from source rocks. Then, on this basis, we profoundly analyzed its controlling action on above-generation and below-storage tight oil reservoirs from the distribution range and overpressure of source rocks in K_2qn^1 formation.

1 Geologic Aspects

The research area lies on the central depression in southern Songliao Basin, which builds on the Paleozoic hercynian fold basement and has the characteristic of upper-fault and lower-depression. Its distribution area of tight sandstone is about 5000km^2 and includes Honggang terrace, Changling sag, Fuxin uplift belt, Huazijing terrace and Southeast uplift etc, a total of five secondary structural belt. In K_2qn^1 formation of Cretaceous period, lake basin of this area expanded large scale and developed a hundred-meter-thick strata, which includes grey-black mudstone, dark grey mudstone, black shale and presents a characteristic of regional distribution. Its kerogen mainly shows as I and II_1 type, and high abundance of organic matter is in mature or high maturity stage, Which provides favorable condition for the migration and accumulation of oil (Huang et al., 2013). Connecting with the predecessors research results (Lu et al., 1995; Cai et al., 2012), when the period was in Nenjiang group about 82Ma ago, mudstone in K_2qn^1 formation whose buried depth greater than 1000m started to mature, but its quantity of hydrocarbon generation and expulsion was small. When the time was 80Ma ago, mudstone in K_2qn^1 formation deeper than 1600m entered into the phase of main hydrocarbon expulsion. At the same time, T2 source fault came into play and the abnormal high pressure in K_2qn^1 formation was released, so that the oil generated from K_2qn^1 formation was pushed into lower K_1q^4 formation and gathered into oil pool. Up to now, Haituozi oilfield, Northern Da'an oilfield, Liangjing oilfield and other tight oil reservoirs were successfully exploraed in this area.

2 Evaluation Standard of High-Quality Source Rocks

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（1）assessment system of organic matter abundance

More and more scholars deem that the source rocks begin to expel hydrocarbon when its hydrocarbon-generation amount equals to hydrocarbon-expulsion amount, which is referred to as "effective source rocks". On this basis, if there is an obvious turning point between hydrocarbon-expulsion amount and TOC^0 (original organic carbon content), but also the increasing rate of hydrocarbon-expulsion amount located above the turning point faster than those under the turning point, then the source rocks above the turning point is called "high-quality source rocks" (Lu et al., 2012). What's more, source rocks located under the point can be divided into two kinds. The one is effective source rocks which has the capability of hydrocarbon expulsion and the other one is invalid source rocks which can't discharge hydrocarbons. We can see from figure1 that the source rocks lack capability of hydrocarbon expulsion whose TOC^0 below1.0%. When its TOC^0 fall in between 1.0% and 2.5%, the source rocks begin to expel hydrocarbons but its speed is very slow and the maximum amount of hydrocarbon-expulsion is 8mg/g (Table 1).However, when its TOC^0 greater than 2.5%, the oil discharge amount is clearly on the rise with the increase of TOC^0. Obviously, 1.0% and 2.5% correspond, respectively, to the values of lower limit with organic matter abundance of effective source rocks and high-quality source rocks. But what we want to emphasize is this: TOC^0 that this paper mentioned is not residual organic carbon content but also original organic carbon content, which lacks the characteristic of ubiquity. So, this paper converts TOC^0 to TOC, using the method of organic carbon recovery by Lu Shuangfang (Lu et al., 1995). After calculation, the lower limit TOC of high-quality source rocks is 2.0% and the lower limit hydrocarbon expulsion of high-quality source rocks is 8mg/g. Accordingly, the lower limit TOC and hydrocarbon expulsion of effective source rocks are 0.8% and 1mg/g respectively (Table 1).

（2）assessment system of organic matter maturity

Whether or not the source rocks can contribution in terms of hydrocarbon accumulation, depending on its maturity and the ability of hydrocarbon-expulsion (Cai et al., 2012). In this paper, we introduce the concept of $(S_1+S_2)/TOC$ to represent the maturity of organic matter, and divide the expulsion threshold of hydrocarbon by using its variable characteristics with the buried depth. What can be seen from figure 2a is I type and II_1 type are main organic matter types of source rocks in K_2qn^1 formation, while the content of II_2 type of organic matter is lower and contains almost none of III type of organic matter. What's more, the expulsion threshold of I type organic matter is 1580m and the expulsion threshold of II_1 type organic matter is 1640m, so, we designate it as 1600m in this area, which is corresponding to R_o equals to 0.8%. At this moment, the source rocks enters into maturation phase and begin to expel hydrocarbon. Whereas, the amount of hydrocarbon -expulsion reaches the maximum when the buried depth descends to 1900~2050m, which is corresponding to R_o equals to 0.9% (Fig. 2b). In conclusion, the source rocks can be called effective source rocks when its R_o higher than 0.8% and is known as high-quality source rocks when its R_o exceeds 0.9%. Meanwhile, for those invalid source rocks whose R_o is less than 0.8%, its expulsion capacity of hydrocarbon is almost zero (Table 1).

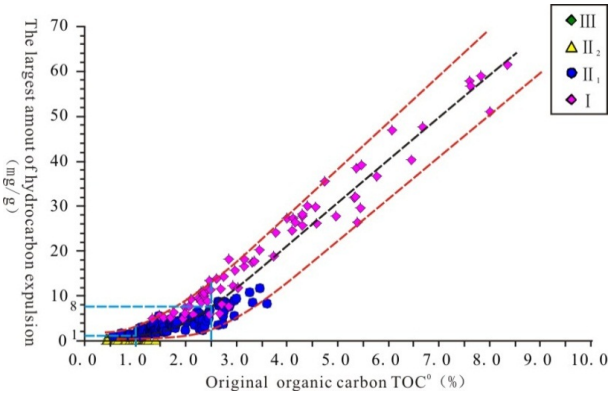

Fig.1. Evaluation standard of source rocks in K_2qn^1 formation at central depression in southern Songliao Basin.

3 Controlling Function of Overlying High-Quality Source Rock on Tight Oil Reservoirs

（1）range of high-quality source rocks in K_2qn^1 formation controls the distribution pattern of reservoir in K_1q^4 formation

Table 1 Evaluation standard of source rocks in K_2qn^1 formation at central depression in southern Songliao Basin

Category of source rocks	Organic matter abundance		Hydrocarbon expulsion amount (mg/g source rocks)	R_o(%)
	TOC^0(%)	TOC (%)		
high-quality source rocks	>2.5	>2	>8	>0.9
effective source rocks	1.0~2.5	0.8~2	1~8	0.8~0.9
Invalid source rocks	<1.0	<0.8	<1	<0.8

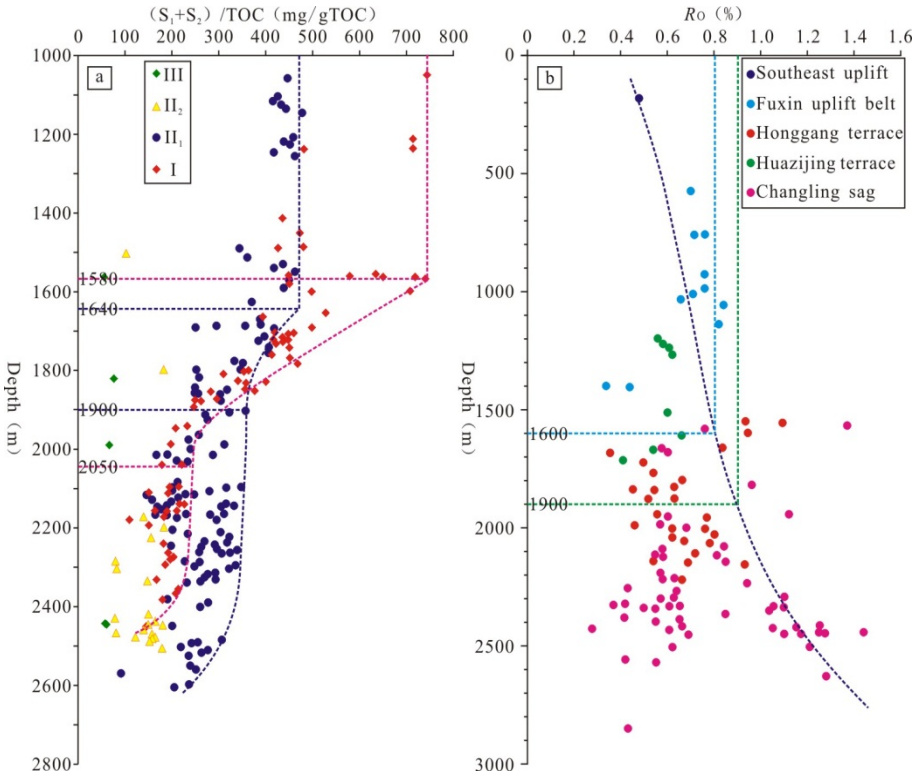

Fig. 2. Evaluation standard of source rocks in K_2qn^1 formation at central depression in southern Songliao Basin.

In the well area of Qian178-Qian176-Qianshen4-Rang53, a typical area of tight oil reservoirs, multilayer reservoir has a great thickness whose productivity is within a scope of 1.3~3.8t/d. From this area to the western or eastern slope, the thickness of high-quality source rocks becomes more and more thin, so that its oil production decrease and water production increase a lot. According to statistics, the thickness of high-quality source rocks and the depth of oil shows is in scale and there is a good correlation between them. In favorable development area of high-quality source rocks, the maximum depth of oil shows can achieve to 180m (Fig. 3a). In spite of the thickness of effective source rocks and the depth of oil is also in scale, their correlation becomes more and more weak (Fig. 3b). As for reasons, there are two. Firstly, the capability of hydrocarbon-generation and hydrocarbon-expulsion of effective source rocks is significantly weaker than high-quality source rocks. Secondly, lower mudstone in K_2qn^1 formation would cut off the oil migration from upside effective source rocks. Obviously, the range and thickness of high-quality source rocks controls the distribution pattern of reservoir in K_1q^4 formation.

(2) Characteristic of overpressure in K_2qn^1 formation controls oil's downward migration depth in K_1q^4 formation

In the period of Qing Shankou formation, Songliao basin expanded very quickly, so that the mudstone of

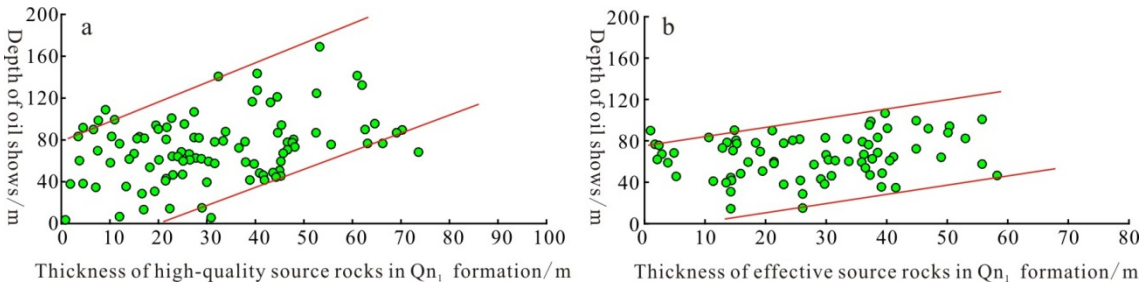

Fig. 3. Correlation diagrams of source rocks in K_2qn^1 formation and reservoir in K_1q^4 formation at central depression in southern Songliao Basin.

K_2qn^1 formation produced ancient overpressure in K_2n^3 formation, owing to the compaction disequilibrium formed in the process of rapid deposition. Later, the value of ancient overpressure increased constantly because of hydrothermal-pressure increasing and hydrocarbon generation and reached 7Ma in the late period of Nenjiang group. Then, the ancient overpressure released for the first time just because that T2 fault activated. After that, structure activity tended towards calming down, which led to the ancient overpressure keep increasing. In the late period of Mingshui group, T2 fault activated and the ancient overpressure released for the second time. Controlled by this mechanism, the third release of ancient overpressure happened at the end of paleogene system. We can see from the overpressure evolution that its first two release time are well matched with the hydrocarbon-expulsion period of K_2qn^1 formation. This point shows that overpressure is the motive force for hydrocarbon migration produced by source rocks in K_2qn^1 formation, which is very important in the migration and accumulation process of above-generation and below-storage tight oil reservoirs.

Through the statistical analysis on the ancient overpressure value and the depth of oil shows, we have found that the development characteristic of overpressure controls oil's downward migration depth. However, due to the complexity of geological conditions, its control action should not be understood as a whole. (1) when T2 opening fault is the primary path for oil migration, oil's vertical migration speed is more faster than lateral migration speed. Then, overpressure's control action on oil migration is the strongest and oil's depth of the downward migration is 150m. (2) When T2 opening fault is scanty and the upper I, II sand groups in K_1q^4 formation are thin, oil's depth of the downward migration can reach 140m but only 100m when the upper I, II sand groups in K_1q^4 formation are thick. As for reasons, the thinner of the I, II sand groups' thickness, the smaller of the oil's migration resistance, so that the attenuation amplitude of overpressure would be more small.

4 Conclusion

To sum up, in K_2qn^1 formation at central depression in southern Songliao Basin, the mudstone whose TOC $\geq$2.0% and $R_o\geq$0.9% is high-quality source rocks, which has a greater ability to generate and expulse hydrocarbon than effective source rocks. In the formation of tight oil reservoirs in K_1q^4 group, the control action of high-quality source rocks is the most remarkable. Its distribution range controls the tight oil's pattern and its overpressure is the migration dynamic for tight oil's migration which controls oil's downward migration depth in K_1q^4 formation.

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