Oil accumulation related to migration of source kitchens in the Lukeqin structural belt, Turpan-Hami Basin, China

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Abstract: The Lukeqin structural belt is the main heavy oil accumulation zone in the Turpan-Hami Basin. The recent discovery of light oil in the Triassic indicates that there may be multiple source kitchens contributing to the oil accumulation. According to oil geochemical analysis and oil-source correlation, the oil in deep and shallow reservoirs of the Lukeqin Oilfield presents different physical and saturated hydrocarbon mass spectrum characteristics. The Triassic heavy oil is from the northern Upper Permian lacustrine source rocks, and the light oil represented by the Yudong-9 Well is from the northwestern Lower Jurassic coal-measure source rocks. The timing of oil charging was determined by K/Ar isotope dating, reservoir fluid inclusion analysis and the evolution history of different source rocks. In summary, the accumulation process consists of two stages. From the end of Triassic to early Jurassic, the northern Permian source kitchen generated a considerable amount of oil, which was finally degraded to heavy oil, migrated to the south and then accumulated. The northwestern Jurassic coal-measure source kitchen began to generate oil at the end of Cretaceous, while the northern source kitchen could only generate a little hydrocarbon. The heavy oil and the light oil have different source rock locations, migration directions and accumulation times. The migration of hydrocarbon source kitchens affects the distribution of heavy oil and light oil reservoirs at the present time.

Key words: Source kitchen, light oil, oil-source correlation, timing of oil charging, Turpan-Hami Basin

1 Introduction

The Lukeqin structural belt located in the western part of the Tainan Sag is a heavy oil enriched zone (Yin, 1997). A heavy oil show was discovered in the Aican-1 Well in 1995, and commercial heavy oil was discovered in the Triassic Karamay Formation in Yudong-1 and Yu-1 wells. Previous studies have shown that the Lukeqin structure is in the area where the source rock of the Permian Taodonggou Group (P₂) was deposited (Zhao et al, 1998; Li et al, 2004). However, due to the continuous uplifting since the end of the Triassic, the Permian and its overlying strata in the Lukeqin structural belt are of low maturity and much thinner than those in the Taibei Sag (Tu et al, 1998; Li et al, 2000; Jin et al, 2006). Exploration wells drilled through the Permian did not encounter oil and gas shows, so the Permian should not be the major source rocks of heavy oil in the Lukeqin structural belt (Wang et al, 2007). Based on the oil/water contact dipping from south to north and from east to west, and the northwest-

dipping nose shaped structure in the area since the end of Triassic, we can infer that the oil in the Lukeqin structural belt may have come from the Taodonggou Group in the Taibei Sag dipping to the northwest. The palaeotemperature of the Permian source rocks in the Taibei Sag reached 80-100 °C, which means that the oil and gas generated in the Permian might have migrated and accumulated in the early Jurassic. Since the large scale uplifting of the Huoyanshan fault-anticline belt occurred in the late Cretaceous to Tertiary, the hydrocarbon originating from the Permian in the Taibei Sag migrated updip from north to south and reached the Lukeqin heavy oil belt before the uplifting (Yang et al, 2005; Li et al, 2006).

With the increase of exploration in recent years, the discovery of light oil in Triassic reservoirs breaks the traditional concept about hydrocarbon migration and accumulation, and indicates that there may have been more than one hydrocarbon source kitchen in this area. A clear understanding of the relationship between oil and sources, the distribution of source kitchens, migration pathways, and timing of hydrocarbon accumulation may lead to new discoveries (Rangel et al, 2003).

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2 Geological setting

The Lukeqin structural belt, located in the Tainan Sag on the south of the Turpan Depression in the Turpan-Hami (Tuha) Basin, is the only pre-Jurassic heavy oil enriched zone discovered in the basin. So far nearly 100 million tonnes of oil reserves have been discovered. The overall structure is a large-scale nose shaped uplift gradually dipping from east to west. The Lukeqin area is mainly controlled by faults, with

the intersection of faults in the main parts of the structure. The NW-trending faults control the strike of the structural belt, and the NE-trending faults cut the structural belt, forming a grid-shaped fracture framework. At present, the discovered oil traps are fault blocks in such a structural setting. Two oil-bearing intervals are developed in the Middle-Upper Triassic Karamay Formation (T₂k) and Middle Jurassic (J₂), respectively (Fig. 1).

Fig. 1 Regional geological map and strata section of the Lukeqin structural belt

3 Characteristics of crude oil and analysis of oil sources

The Triassic heavy oil in the Lukeqin structural belt is characterized by a relatively low carbon isotope value. The δ¹³C value of oil is from -30.22‰ to -30.01‰, which indicates a typical sapropel organic facies (Wang et al, 2003; Chen et al, 2004). The GC-MS characteristics are high abundance of n-alkanes with a post-peak pattern, a high content of β-carotane, a relatively high content of tricyclic terpane and gammacerane, a specific content of pregnane and homopregnane, a low content of diasteranes, and $\alpha\alpha\alpha 20RC_{27} < \alpha\alpha\alpha 20RC_{28} < \alpha\alpha\alpha 20RC_{29}$ of regular sterane, showing “/” shape in the mass spectrogram of m/z=217, indicating a high degree of maturity (Fig. 2). The light oil has a lighter carbon isotope ratio. By comparing several mass spectrograms of saturated hydrocarbons from mudstone samples, we find that the characteristic mass

spectrogram of lacustrine source rocks of the Taodonggou Group of the Aican-1 Well is similar to that of m/z=123 of the Yudong-1 Well (Fig. 3). Based on the evolution of source rocks and the structural evolution of this area, we think that this type of crude oil mainly comes from the lacustrine source rocks of the Upper Permian Taodonggou Group.

The main characteristics of light oil from the Yudong-9 Well are a specific content of tetracyclic terpane, a low content of tricyclic terpane and gammacerane in the mass spectrograms of m/z=191, and $\alpha\alpha\alpha 20RC_{27} > \alpha\alpha\alpha 20RC_{29} > \alpha\alpha\alpha 20RC_{28}$ of regular sterane, showing “L” shape. The Tm/Ts value is large, and the pristane/phytane ratio is 3.27. These characteristics indicate that the crude oil has a high degree of maturity and was generated from coal-measure source rocks (Chen et al, 1999). Owing to $\alpha\alpha\alpha 20RC_{27} < \alpha\alpha\alpha 20RC_{29}$ of coal-measure oil generated in the Taibei Sag (Zhang and Sun, 2008), this kind of light oil may be generated by the Lower Jurassic coal-

Fig. 2 Mass spectrograms of $m/z=191$, 217 of T_3 , T_2k , J_1 thickened crude oil and oil sand asphalt

Fig. 3 Mass spectrograms of $m/z=123$ of Yudong-1 crude oil and saturated hydrocarbon from Aican-1 P_2td source rocks

measure source rocks in the Tainan Sag (Fig. 4).

4 Analysis of timing of oil charging

K/Ar isotope dating confirms that the isotopic age of authigenic illite from the Triassic heavy oil reservoir sandstones is 113.4-199.8 Ma, mainly in the range of 179.3-199.8 Ma. This means that the main formation period of Triassic heavy oil accumulations is Early Jurassic.

According to the reservoir diagenetic sequence, fluid inclusion distribution and freezing point, the fluid inclusions of Triassic heavy oil reservoirs can be divided into two stages (Fig. 5). The homogenization temperatures of the two stages are mainly in the range of 60-70 °C and 90-100 °C, respectively. This reflects that there are at least two stages of oil charging for the Triassic heavy oil reservoirs. The early stage, which is dominant, is from the end of Triassic to Early Jurassic and the late stage is from the end of Early Tertiary to Neocene (Fig. 6).

The test results of two heavy oil sands of the Ma-1 Well in the Machang structure to the east of the Lukeqin structural belt show that the geologic age of authigenic illite of Upper Permian heavy oil reservoir is 175.8 Ma, and that of the

Qiketai Formation heavy oil reservoir (J_2q) is 94.6 Ma. This illustrates that the accumulation periods of the Machang structure and the Lukeqin structure are consistent, both in the Early Jurassic. The accumulation period of shallow heavy oil in the Qiketai Formation is Late Cretaceous. The heavy oil migrated upwards due to the faulting in the Late Cretaceous and accumulated again in the upper Qiketai Formation.

The fluid inclusions of the second stage in the lower part of the sandstone heavy oil reservoir are likely to reflect late light oil charging.

According to the evolution history of source rocks in the Yuxi-2 Well in the northwest of the Tainan Sag, we can find that the Lower Jurassic source rocks became mature relatively late (Fig. 7). They did not enter the mature stage to generate hydrocarbon until the end of the Cretaceous. At present, they have entered a highly mature stage and can generate abundant oil and gas. Since the uplifting of the Huoyanshan structure in the Lukeqin structural belt from the end of the Cretaceous to the Early Tertiary, the oil and gas in northern sag could not migrate to the south. The coal-measure oil in the Lukeqin structural belt formed from the Early Tertiary to the Neocene could only come from the down-dipping coal-measure source rocks which lie northwest of the Tainan Sag.

Fig. 4 Comparison of the characteristics of sterane and terpane between coal-measure light oil in Yudong-9 Well and light oil in the Taibei Sag

Fig. 5 Homogenization temperature of fluid inclusions in the Yudong-2 Well

5 Relationships between migration of hydrocarbon source kitchens and oil accumulation

There are two hydrocarbon source kitchens in the Lukeqin structural belt. Their strata, locations, time of hydrocarbon generation and migration pathways control the migration of oil accumulations.

The study of tectonic evolution shows that the northern Taibei Sag and Lukeqin area were united prior to the Early Yanshan movement and this was favorable for the southward migration of Permian lacustrine oil. The Permian hydrocarbon source kitchen in the northern part of the Lukeqin structural

belt entered the peak of generating and expelling hydrocarbon in the Early Jurassic. The hydrocarbon migrated and accumulated in the southern Lukeqin structural belt (Fig. 8). However, in the Early Jurassic, most parts of the southern Lukeqin structural belt were still being uplifting and denuded, and the accumulated oil was biodegraded and became heavy oil (Ma et al, 2005; Ni et al, 2005). In the late Early Jurassic, the Lukeqin structural belt underwent deposition of coarse clastics and was still in shallow water oxidizing environment. Oil was also biodegraded and accumulations were further destroyed. The fluid inclusions record the charging process of hydrocarbon from Late Triassic to Early Jurassic and show that the aqueous phase had a low salinity (the salinity of brine inclusion is 3.5%-5.2% NaCl). The reservoir is in a relatively open environment. During the deposition of the Middle Jurassic Xishanyao Formation, the Lukeqin structural belt received deposits gradually. The degradation, water washing and destruction of Triassic reservoirs weakened gradually, and the reservoirs entered the preservation stage in the Middle Jurassic (Zeng and Zuo, 2002; Su, 2004).

In the Late Cretaceous, the Carboniferous and Permian source rocks in the Lukeqin structural belt could also generate and expel hydrocarbon that migrated vertically through faults and accumulated in Triassic heavy oil reservoirs. Because of the low rate of hydrocarbon generation and expulsion, less oil and gas was charged. The fluid inclusions record this

Fig. 6 Relationship between burial history and Triassic oil charging in the Yudong-2 Well

Fig. 7 Burial history and evolution history of source rocks of the Yuxi-2 Well in the northwest of the Tainan Sag

charging process and show that the aqueous phase had a high salinity (the salinity of brine inclusion is 11.0%-21.4% NaCl). The reservoir is in a viscous flow environment, favorable for hydrocarbon preservation. The original heavy oil was diluted owing to late oil and gas charging. The saturated hydrocarbons in crude oil are also related with hydrocarbon charging.

From the end of the Cretaceous to the Early Tertiary, the

oil generated by the mature Lower Jurassic coal-measure source rocks in the northwestern Tainan Sag entered the Triassic sandstones through unconformities at the top of the Triassic and faults, forming light oil accumulations (Yudong-9 Well, light oil reservoir at the top of Triassic). We can infer that the oil generated by the coal-measure source rocks could also migrate along Jurassic sandstones to the updipping Lukeqin structural belt (Fig. 9).

Fig. 8 Model of heavy oil migration and accumulation in the Lukeqin structural belt from the end of Triassic to the Early Jurassic

Fig. 9 Model of light oil migration and accumulation in the Lukeqin structural belt (Northwest-southeast section)

As a result, there exist differences between the location of source rocks, the migration direction, and the accumulation time of heavy oil and those of light oil in the Lukeqin structural belt. The migration and evolution of hydrocarbon source kitchens control the formation and distribution of heavy and light oil accumulations (Fig. 10).

6 Conclusions

In the Lukeqin structural belt, there are two kinds of oil with different sources. Analysis of accumulation processes shows that the distribution of heavy oil and light oil reservoirs in the Lukeqin structure is mainly controlled by two hydrocarbon source kitchens of different periods.

The formation and distribution of heavy oil in the Lukeqin structure is controlled by the northern Permian hydrocarbon

source kitchen. Its main oil generation occurred in the Late Triassic-Early Jurassic.

The Lower Jurassic coal-measure hydrocarbon source kitchen in the northwest of Tainan Sag controls the formation and distribution of coal-measure oil, which was generated at the end of the Cretaceous to Tertiary. The favorable area for coal-measure oil may be in the high positions in the southeast.

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Fig. 10 Distribution map of hydrocarbon source kitchens and oil accumulations in the Lukeqin structural belt

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