The migration and accumulation conditions and the exploration prospects in large low permeable lithologic oil fields—China Ordos basin as an example

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In recent years, many large-scale oil and gas fields of medium and low abundance have been found in the land, which are having the characters of low porosity, low abundance and large reserves, etc. Researches show that the syncline area of large depression basin in China’s land has a good prospect finding large-scale lithologic reservoirs (Fig. 1). In this paper, the upper Triassic low permeability reservoir of Mesozoic of Ordos basin as an example, it introduced the forming conditions, accumulation mechanism and exploration prospects of large-scale low permeable lithologic oil and gas fields.

1. Regional geology

The Ordos basin, which is located in the Shanxi, Gansu, Ningxia, Mongolia, and Shaanxi provinces across north-west China, is a typical craton-edge superimposed basin that is composed of six first-order tectonic units (Fig. 1). The Triassic Reservoirs are vertically distributed across the Yanchang Formation of the Upper Triassic-Mesozoic Plane, mainly throughout the Tianhuan depression and the central and southern of slopes of Yishan (Fig. 2).

2. Sediment

The strata of the Upper Triassic Reservoirs were formed by the Yanchang Formation. From top to bottom, the strata of the Upper Triassic Reservoirs are divided into 10 sections: Chang1~10. The Yanchang Formation generates hydrocarbons and serves as the reservoir system for the landlocked Ordos Basin. It is also the primary site for determining how the basin was formed. According to the sequence-stratigraphic division, Chang 7~10 are classified as the lacustrine-transgressive stage, i.e., the water is becoming shallower and the basin is gradually expanding, the water is becoming deeper, and most sediment is classified as coarse to granular. Chang 1~6 are classified as the water-regression stage, i.e., the water is becoming shallower and the basin is gradually drying. The lithologic combination consists mainly of rhythm deposits, which are composed of thick gray layers of massive fine-grained sandstone, siltstone, and dark grey mudstone. The general characteristics of this ancient terrain are high in the north and east and low in the south and west.

3. Conditions for hydrocarbon generation

Source rocks in Chang 7 of the Yanchang Formation were formed in a large inland lake, which mainly consisted of thick black oil shale that was very thick, widely distributed, rich in organic matter, and very mature. The main hydrocarbon fields that have been found in this area are located within the hydrocarbon deposition and its surrounding sand belts. The spatial distribution of the hydrocarbon source rocks of Chang 7 controls the distribution of the Mesozoic oilfields (Fig. 3).

4. Reservoir conditions

It developed in the northeast and southwest, which are the two major source areas for that formed the Yanchang Formation, and was deposited near the river and lake clastic rocks. The location where the river delta sand, mouth bar, distal bar, front sheet sand, gravity flow-related sandy debris, and turbidite flow into the central lake constitute a contiguous overlay for the construction of the reservoir. Although the area is subject to strong compaction, its properties are not conducive to the preservation of porosity, resulting in low porosity and permeability (Fig. 4). Research has shown that two-thirds of the reservoirs only slightly porous and permeable (Fig. 5).

5. Relationship between the source-reservoir-cap assemblage and the reservoir

The Yanchang Formation can be divided into five sets of source-reservoir-cap assemblages.
6.2 Critical properties of the main accumulation stages

As an example, the JY oilfields separated into three steps that determine the critical properties of the reservoir during the main accumulation stages.

1. To determine the lower limit of the current reservoir properties, the lower limit of the porosity of the oil reservoir in Chang 4+5 group is set at 4.7% and the lower limit of permeability is set at 0.02md.

2. To ensure proper oil and gas filling times based on the fluid-inclusion research performed in the sandstones areas of Chang4+5 of JY, the main accumulation period is believed to be the middle of the early Cretaceous period (125Ma).

3. To ensure proper variation in porosity after the filling of the reservoirs and other critical properties during accumulation, the largest buried depth was increased to 450 m and the porosity variation (ΔΦ) was set to 5.5%. Therefore, the critical porosity of the meandering river delta front distributary channel of the JY Oilfield (Chang 4+5) is defined as follows: ΔΦ = 0.15 = 10.2%.

Similarly, we calculated that the critical porosity is 10.16% for the meandering river delta front distributary channel during the accumulation stage in AS oilfield (Chang6). The critical porosity is 10.8% for the braided fluvial river delta front distributary channel in XF oilfield (Chang8) during the accumulation stages. These findings show that during the main accumulation period the critical porosity must be 10% in order to fill the reservoir oil.

6.3 Accumulation periods and evolution

Reservoir formation requires 2-3 accumulation stages. Early accumulation occurs under highly porous conditions. Accumulation and compaction occur at the same time during the filling process.
For example, in the XF oilfield there are three phases to the oil-filling process at the Chang 8 reservoir. Dark, yellow, and blue 3 period asphalt were found using fluorescent photos (Fig 8). Oil was present in between alternating diagenetic layers. Secondary kaolinite was mostly subject to disseminating asphalt, indicating that the formation of secondary kaolinite occurs before filling with crude oil and is closely related to oil and gas filling. Clay minerals formed a film on the inner surface of the pore, where yellowish-white fluorescent asphalt constitute some of the particles and blue and white fluorescent crude oil were able to subsequently fill in the pores that were wrapped in the film. Hydrocarbons inclusions reflect the three phases of hydrocarbon filling. These processes occurred over mid-late Jurassic, mid-early Cretaceous, and the late-early Cretaceous periods (Fig 9, Fig 10).

Three oil and gas charges, along with three clear regions of quartz overgrowth or chloritization (Fig 11, Fig 12), caused densification of the reservoir, thereby forming the low-permeability reservoir that exists today.

7 Reservoir distribution and exploration prospects

The poor abundance of reserves and contiguous distribution of small lithologic reservoirs resulted in the formation of a large composite field. The northeast river delta depositional system in the Shahezi region (Chang 8) serves as an example (Fig 13), the tectonic background has a large, western-leaning slope, and the reservoir distribution consists only of a delta front underwater distributary channel that consists of fine-grained sandstone within the distribution of the hydrocarbon source rocks; here, the thickness is thinner and the physical properties are poor. The abundance of the reservoirs is (9.65-13.24)x10^(-4) t/km². A single reservoir is between 100-250m wide and 1000-1500m long, the contiguous, overlaying distribution of reservoirs forms a large oil district. However, the coarse sandstone of the distributary channel of the delta plain, without the distribution of the hydrocarbon source rocks, contains almost no oil even though the thickness is greater. The distribution is wider, and the physical properties are better. Because of these reasons, low-porosity and low-permeability sandstone can accumulate because it serves as an oil source, due to its high porosity during the accumulation stages, which allows for the easy formation of a reservoir. Subsequently, due to diagenesis, properties worsened, and the dip direction formed a dense layer that blocked out the reservoir, allowing the initial reservoir to form without damage. However, it was difficult to form a high-porosity and high-permeability sandstone reservoir because it was far away from the oil source and because it serves as a migration channel for oil and gas; resulting in the dip direction occurred spilling lacking of imperious stratum. Therefore, the distribution of the reservoirs has nothing to do with structure, but is instead influenced by source rocks, sedimentary facies and the properties of the reservoirs.

The above discussion indicates that the delta front underwater distributary channel, mouth bar, remote sand bar, lake center, gravity flow deposits on the sandy debris flow, slump deposits, and turbidites are the most favorable exploration targets for hydrocarbon source rocks within Chang 7. The distribution of sand is very broad and contiguous and there good prospects for exploration. Due to development in process technologies, low permeability, low permeability sandstone reservoir, as well as tight sand reservoir within the source rocks will become the main site for exploration and development.

8. Conclusion

- Thin layer, high-quality hydrocarbon source rocks that are distributed over a large area provide a significant source of hydrocarbon;
- High-diagenetic, low-porosity and permeability, and heterogeneous constitute a major space for the accumulation of oil and gas;

Several source-reservoir-roof layers make up the "sandwich" structure that provides good conditions for accumulation and blocking;
- The large delta causes the formation of large vertical and horizontal sandy areas that compound distribution and gravity flow to the sandy bodies provides lithologic traps;
- The reservoir first experienced the accumulation process, then compaction. In the beginning and at locations closer to the source, increased planar filling resulted in the formation of the large area of the reservoir due to the high porosity conditions;
- The low abundance and a small contiguous distribution of lithologic reservoirs subsequently formed a large composite field that could yield good exploration prospects.

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