Main Controlling Factors for the High Production of Tectono-Stratigraphic Reservoirs in Continental Down-Faulted Basin

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Abstract. Huoduomoer structural zone is one of the most favorable oil and gas accumulation zones in Beier depression of Hailaer basin. However, the exploration in this zone has experienced a long and tortuous process, and the exploration is almost stagnant until the natural production capacity of well x1 has obtained daily output of 472m³, which has achieved a major breakthrough in the exploration of tectono-stratigraphic and stratigraphic unconformity reservoirs in this structural zone. Based on the comprehensive study of the subdivided layers of the structural belt, this paper holds that the Nantun Formation suffered from long-term denudation after deposition, the Nantun Formation at the high part of the uplift belt was denuded completely, and the remaining Nantun Formation at the periclinal area was the main target layer for exploration. Based on the analysis of the main controlling factors of hydrocarbon accumulation, it is considered that feldspar lithic sandstone and lithic sandstone mainly developed in the subaqueous distributary channel deposition of braided river delta front are easy to be leached and eroded, forming high-quality reservoir with secondary porosity near the unconformity surface, and the multi-direction oil and gas migration system is the key to the oil and gas accumulation; the stable and thick mudstone deposition in the large section provides a good sealing condition for traps.

1. Introduction

Tectono-stratigraphic reservoirs are widely developed in continental fault basins, but they are mostly hidden in the middle of the main target strata. In the early exploration with structural traps as the exploration target, structural interpretation focuses on the top of large target strata, often neglecting the internal details, which makes such reservoirs difficult to be found and predicted. In a delicate phase of exploration, due to the wide application of new geological and seismic technologies and new methods, such as subdivision technology, oil-gas migration and accumulation technology, reservoir prediction technology, etc., great breakthroughs have been made in tectono-stratigraphic reservoirs.

Beier depression is the largest depression in Hailaer basin, about 3010km². The Huoduomoer structural belt is an important positive structural belt in Beier depression, which is adjacent to the important hydrocarbon-generating sag, the Beixi sag. High quality source rocks are developed in the first member of the Nantun Formation of the Beixi sag. The high quality source rocks have the characteristics of wide area, large thickness and good quality [1], three large-scale reservoirs have
been found in the main target Nantun Formation of the Beixi sag, with proved reserves of more than 70 million tons.

Fig 1. Interpretation and distribution of residual fine stratification in Huoduomoer structural belt

2. Basic characteristics of reservoirs in Huoduomoer structural belt

The basement of Huoduomoer structural belt is Paleozoic epi metamorphic rock, and the Cretaceous sedimentary strata are mainly Tongbomiao Formation, Nantun Formation, Damoguaihe Formation, Yimin Formation and Qingyuangang Formation from bottom to top, followed by Paleogene and Neogene [2, 3]. The first member of Nantun Formation is the main oil-bearing stratum.

2.1. Structural characteristics

Based on the analysis of the structural evolution, it is considered that the Huoduomoer structural belt is an inherited paleouplift formed by long-term structural activities. After the deposition of Nantun Formation, the tectonic uplift causes the strata of Nantun Formation to be denuded completely in the high part of the structure, and then it sank again and deposited the extremely thick Damoguaihe Formation. In order to make a more detailed study of Nantun Formation, the first member of Nantun Formation is subdivided according to the characteristics of sedimentary cycle, which is divided into six lithologic sections, and the interpretation of subdivided lithologic sections is carried out after fine calibration of well earthquake. The internal strata of Nantun Formation show the gradual expansion of denudation range from the bottom to the top, and the residual strata gradually thicken from the high part to the low part of the structure (Fig. 1). Structural traps and structural stratigraphic traps formed on the unconformity surface of each stratum.

2.2. Features of source-reservoir-cap rock combination

According to the drilling results, there are three sets of source reservoir cap combinations in the Huoduomoer structural belt, and they are as follows from bottom to top:

(1) The lower reservoir cap combination is composed of bedrock buried hill and Cretaceous Tongbomiao Formation mudstone. The combination has good conditions for oil and gas migration and accumulation [4]. But the mudstone distribution of Tongbomiao Formation is limited and does not play a good sealing role.

(2) The middle combination is composed of the first member of Nantun Formation in Cretaceous and the first member of Damoguaihe Formation overlying mudstone. This combination is the most important reservoir cap combination in this structural belt. At present, the main oil wells, such as X1,
(3) The upper reservoir cap combination is composed of thick sandstone and thin mudstone in the upper part of the second member of Damoguaihe Formation. The upper part of the second member is mainly composed of a large set of delta front sandstone deposits, with thin mudstone. The oil mainly migrate upward through the oil source fault connected with the first member of the Nantun Formation, forming a small secondary oil reservoir [5].

Table 1. The relationship between oil and gas distribution and unconformity surface of each well in the hodomore structural belt

| well | oil layers | lithology | sedimentary microfacies | test result (m³/d) |
|------|------------|-----------|-------------------------|-------------------|
| X1   | N2, N11    | glutenite | subaqueous distributary channel | 427               |
|      | N12, N13, N14, N15, N16 | | | |
| X34  |            | glutenite | subaqueous distributary channel | 1.44              |
|      |            | | | |
| X54  |            | glutenite | subaqueous distributary channel | 50.41             |
|      |            | | | |
| X33  |            | glutenite | subaqueous distributary channel | 7.20              |
|      |            | | | |
| X45  |            | glutenite | subaqueous distributary channel | 28.8              |
|      |            | | | |
| X10  |            | glutenite | subaqueous distributary channel | 0.60              |
|      |            | | | |
| X50  | Denudation area | glutenite | subaqueous distributary channel | 18.55             |
|      |            | | | |
| X53  |            | glutenite | subaqueous distributary channel | 134               |
|      |            | | | |
| X32  |            | Fine stone siltstone | Sheet sand | 2.39               |
|      |            | | | |
2.3. Reservoir types

According to reservoir cap combination and current drilling analysis, the structural belt mainly develops the following three types of oil and gas reservoirs:

1. Structural reservoir

Structural reservoirs are mainly developed in bedrock buried hill and upper part of the second member of Damoguaihe Formation. At present, the bedrock buried hill oil reservoir and the second member of Damoguaihe Formation oil reservoir drilled in H 2 well are all structural oil reservoirs.

2. Structure-stratigraphic complex reservoir

The strata of the first and second members in Nantun Formation of the top of the structural belt were denuded to varying degrees, and the residual strata are gradually thickened towards the periclinal area. The unconformity surface at the top of the structural belt is covered by a large section of thick mudstone, forming a large-scale structure-stratigraphic complex reservoir, and the oil in each section are mostly distributed near the unconformity surface (Table 1). At present, the reservoirs of X1 and X53 are all of this type.

3. Lithologic reservoir

The reservoirs in the first member of Nantun Formation is mainly braided river delta front deposit, with different scales of lithologic bodies. Due to the uplift of the structure, especially in the periclinal slope, lithologic reservoirs are easy to form. At present, the lower reservoir of well H3 is the lithologic reservoir formed by sandstone updip and pinch out (Fig. 2).

3. Main controlling factors of high production and enrichment in Huoduomoer structural belt

3.1. Key factors for oil and gas accumulation in the structural belt are the inherited paleoupift and the multi-directional oil supply from the surrounding hydrocarbon generating depression to the high part of the structural belt, forming the convergence flow and fault convergence

In the north, west and south of the Huoudomoer structural belt, a section of high-quality source rock in the first member of Nantun Formation is developed, which makes the structural belt in the favorable position of multi-directional oil supply for a long time. Under the action of fluid potential energy [6], oil and gas migrate from the high potential area of the depression to the low potential area of the high
position of the structure. The Huoduomoer structural belt has good conditions for converging flow and fault convergence, which is very favorable for the scale accumulation of oil and gas. The braided river delta sandstone from the east overlaps with the source rock towards the southwest, forming a good lateral migration channel; the unconformity formed by the long-term sedimentary discontinuity at the top of Nantun Formation also provides a convenient and smooth migration channel for the lateral migration of oil and gas; the fault, fracture system, sandstone and unconformity created by multi-stage tectonic movement form a network of the migration channel system[7] [8], which makes the migration of oil and gas smooth and fast (Fig.3), and it is easy to form large-scale oil and gas reservoirs.

3.2. The deposition of underwater distributary channel sandstone in braided river delta front and the secondary pores formed by later weathering and leaching are the basis for the development of high-quality reservoirs[9]

In the first sedimentary period of the first member of Nantun Formation of Huouomoer structural belt, the braided river delta sedimentary system from the eastern provenance is developed. In the Huoduomoer structural belt, subaqueous distributary channels and sheet sands of the front of fan delta are mainly deposited. After the deposition of Nantun Formation, the structural belt continues to rise and is subject to long-term weathering, leaching and denudation. The strata in the second and first members of Nantun Formation at the top of the structure are basically denuded. As a result, a relatively thick layer of the first member of Nantun Formation is left in the structural encirclement (Fig. 2). The buried depth of the structural belt is shallow, mostly between 1300-1600m, and the primary pores are well preserved, which creates a congenital condition for the development of high-quality reservoirs. The reservoir which is mainly composed of feldspathic lithic sandstone and lithic sandstone has been subjected to weathering and denudation, atmospheric precipitation leaching and other effects for a long time, which makes the dissolved pore in this area develop and the physical properties of the reservoir become better. Various pore types such as primary pore, intergranular dissolved pore, dissolved pore in lithic grain, dissolved pore in feldspar grain and mold pore are developed. The secondary pore is most developed 0-50m away from the unconformity surface, with the weakening of dissolution, the porosity gradually decreases, and the secondary porosity development zone can reach about 180m, which creates conditions for the enrichment and high-yield of oil and gas.

![Fig 3. Model graph of hydrocarbon migration in structural belt of Huoduomoer](image-url)
3.3. A good trap preservation condition is the guarantee of oil and gas enrichment and high yield

Structural stratigraphic and structural lithologic traps are developed in the periclinal area of Huoduomoer structural belt, and multiple reverse normal faults are formed due to strong structural activity. The traps formed by combining with lithology and stratum are easier to accumulate oil and gas, and they are characterized by high oil and gas column and high abundance.

After a long period of weathering and denudation, the Huoduomoer structural belt sank again after sedimentation in Nantun Formation, depositing the first member of Damoguaihe Formation mudstone with a thickness of more than 200m, directly covering the unconformity. This set of mudstone has a stable horizontal distribution. Although there are many structural movements in the later stage, it has a good sealing effect on the preservation of oil and gas due to its large thickness and horizontal stability.

According to the drilling test, most wells can obtain higher natural production capacity without any fracturing modification measures, especially the system test of well X1 from 4mm nozzle to 10 mm nozzle, the oil pressure drop is small, but the production is greatly increased, and the high production of 472m³/day is obtained by flow, indicating that the formation pressure is sufficient; the natural production capacity of well X2 is 147m³/day, and the oil column is 250 m high, indicating that the trap is well preserved, which provides a guarantee for the high and stable production of oil and gas.

4. Conclusion
(1) The Huoduomoer structural belt is an inherited paleouplift formed by long-term tectonic activities. The Nantun Formation suffered a long-term denudation after deposition. The Nantun Formation at the high part of the uplift belt was denuded completely, and the remaining at the periclinal part is the main target strata for exploration.

(2) Under the influence of denudation, stratigraphic traps, structural stratigraphic traps, structural traps and other trap types are mainly developed in the first member of Nantun Formation. Oil and gas reservoirs are mainly structural stratigraphic and lithologic stratigraphic

(3) In the first member of Nantun Formation, feldspathic lithic sandstones and lithic sandstones are mainly developed in the subaqueous distributary channel deposits of braided river delta front, which are easy to be leached and eroded, forming a high-quality reservoir with developed secondary pores near the unconformity surface.

(4) The multi-directional oil-gas migration system created by convergence flow and fault convergence is the key to oil-gas accumulation in this structural belt.

(5) The stable and thick mudstone in the first member of Damoguaihe Formation provides a good sealing condition for the trap.

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