Evolution of prototype basin and analysis of lithofacies paleogeography in Hongqi depression

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Abstract: Based on the analysis of three-dimensional seismic data in Hongqi sag, it is clear that the structure of the depression is controlled by volcanic mechanism, controlled subsidence fault and secondary fault. The structure is complex. The structural framework of the residual basin changed greatly due to the multi-stage tectonic movements. It is not conducive to the understanding of the prototype and lithofacies paleogeography of the depression. Through the study of the recovery of the prototype basin in the key period, the basin prototype of different construction and transformation periods is constructed. The paleogeographic characteristics of lithofacies in different periods are determined. Then, combined with the analysis of single well facies, lake water advance and retreat and sediment supply conditions, the lithofacies paleogeographic characteristics of different periods are determined. The sedimentary period of Tamulangou formation developed a lithofacies paleogeographic pattern of coexistence of volcanic rocks, fan delta and lakes. During the sedimentary period of Tongbomiao formation, the lake basin develops. But the water body is shallow. The material source is sufficient. The fan delta shallow lake sedimentary assemblage is developed. During the deposition period of Nantun formation, the lake basin further expanded rapidly. The water body became deeper. The lake basin became larger. The fan delta shrank. It is fan delta lacustrine sedimentary assemblage. The sedimentary period of Damoguaihe - Yimin formation is a fan delta lacustrine sedimentary assemblage dominated by lacustrine deposits.

1. Preface

The research of prototype basin is of great significance to the study of reservoir distribution in fault basin. The concept was put forward in the 1980s. Prototype basin is a basin produced by a single dynamic mechanism. It has specific settlement type and structure body. There are relatively stable tectonic environment, dominant settlement mechanism, sedimentary filling combination and defined basin boundary in different evolution stages. Such sedimentary basin entity is called prototype basin. With the continuous improvement and development of relevant theories and methods, especially the development of geophysical technology, the spatial distribution characteristics of prototype basins are more accurate and more effective to define the change rules of subsidence center and sedimentary center in different periods. Combined with the analysis of tectonic evolution, the control role of prototype basin on source rocks, sedimentary facies and accumulation is clarified, which has important guiding significance for the next exploration.

Hongqi depression is located in the fault depression zone in the middle of Hailar Basin. It has the characteristics of residual basin. Oil and gas are seen in many wells in the depression. In recent years, Hongqi sag has broken through industrial oil flow pass and has certain resource potential. On the basis
of 2D seismic data, the predecessors restored the prototype of the basin and considered that the changes of sedimentary center and subsidence center in Hongqi sag were characterized by "seesaw" evolution. The subsidence center of the early depression is close to the East. The settlement center of the late depression is near the west side \(^{(1)}\) (Zhang Xiaodong, 2019). Based on the new 3D seismic data, this study is to further deepen the understanding of the prototype basin. It analyzes the structural evolution and lithofacies paleogeographic characteristics. It guides the next exploration direction.

2. Geological Survey

Hongqi sag is located in the north of Beierhu depression in Hailaer Basin. The strike is NE. The area is about 840km\(^2\). The basement of the depression is Hercynian Indosinian granite, and Jurassic and Cretaceous rocks symbiosis of Jurassic Tamulangou formation (J\(_3\)tm), Cretaceous Tongbomiao formation (K\(_1\)t), 1st member of Nantun formation (K\(_1n1\)), 2nd member of Nantun formation (K\(_1n2\)), 1st member of Damoguaihe formation (k\(_1d1\)), 2nd member of Damoguaihe formation (K\(_1d2\)), 1st member of Yimin formation (K\(_1y1\)), 2nd and third member of Yimin formation (K\(_1y2 + 3\)). Tongbomiao and Tamulangou formations are the main exploration target layers.

3. Structural characteristics and evolution

3.1. present structural characteristics

Hongqi sag is a dustpan fault depression of single fault with echelon arrangement, faulting in the West and overtaking in the East. There are three sub depressions from south to north. The order is Ganggangtu sub sag, Shutenor sub sag and Hongqi ranch sub sag. It has a structural pattern of "multi convex and multi depression". The depression is controlled by volcanic apparatus, fault and uplift, and three kinds of depression structures are developed. The southern Ganggangtu sub sag is the fault depression of single break tilting type. The transition zone between the sub sags is the double skip type fault depression of stepped type. The middle shutenor sub sag and the northern Hongqi ranch sub sag are dustpan fault depressions of single fault trough type (Fig. 1). Ganggangtu sub sag is located in the southern basin. The development of the sag is small. The boundary controlled fault and Wuxingdui uplift jointly control the structure and stratigraphic distribution of the sag. The seismic profile shows that with the strong extension of the boundary controlled fault, the Tamulangou formation and Tongbomiao formation in Ganggangtu sub sag rotate and tilt. The gentle slope stratum is seriously eroded. It forms the dustpan fault depression structure of single fault tilt. The sedimentary period of n_1 formation is at the end of fault depression. The sedimentary period of n_2 section has the characteristics of fault depression transition period (Fig. 1cc' ).}

![Figure 1. Structural maps of different depressions in Hongqi sag.](image-url)
The characteristics of fault depression in Shutenor sub sag of n2 are obvious. The lake basin is getting bigger. The area is controlled by boundary controlled fault, secondary controlled fault and volcanic mechanism, and develops single fault trough depression structure. The seismic profile shows that the boundary controlled fault controls the deposition of the early strata in the sub sag, and the secondary controlled fault F1 controls the deposition of n2 section. The strata near the fault F1 is obviously thickened and wedge-shaped. The strata far away from the fault F1 are thinner. The settlement center of n2 section is obviously close to the fault F1 (Fig. 1AA'). The structure of Hongqi ranch sub sag is similar to that of shutenor sub sag in the middle, which is also the dustpan fault depression of single fault trough type.

The two transition zones between the three depressions are all controlled by depression faults and volcanic institutions. They form the double skip type fault depression of stepped type (Fig. 1BB').

3.2. structural evolution characteristics

The structural evolution characteristics of Hongqi sag are consistent with the regional structural evolution history of Hailaer Basin [2-4]. It has experienced three stages of construction and transformation. The three stages of construction are fault depression stage (deposition period from Tamulangou formation to Nantun Formation), fault depression transition period (deposition period from Damoguaihe Formation to Yimin formation) and depression stage (deposition period of Qingyuangang formation). They all experienced a strong tectonic transformation at the end of the three formations.

The seismic profile shows that a series of anticline structures are developed along the depression strike near the trough area of Hongqi depression (Fig. 2). According to the sedimentary characteristics of the strata in the seismic section, the thickness of n2 section in the high part of anticline is thin. The thickness of the two sides increases gradually. The stratum deposition thickness is the largest at the syncline part on both sides of the anticline. It can be seen that the strata on both sides of the anticline has the onlap phenomenon to the high part of the structural. The top deposition of n2 section is truncated. This feature is not obvious in the strata of d1 section and above. It shows that there are compressional uplift and denudation movement from the end of n1 section (the early stage of n2 section) to the end of n2 section. Therefore, the tectonic movement at the end of n2 section controls the formation of the paleostructure.

According to the analysis of burial history and thermal history, the vitrinite reflectance at the bottom of Tamulangou formation and Tongbomiao formation reached 0.5% - 0.7% during the sedimentary period of Nantun Formation. In this period hydrocarbon generation began. But the amount of hydrocarbon generation was small. During the deposition period of Yimin formation, the vitrinite reflectance of Tamulangou formation and Tongbomiao formation reached the stage of medium maturity to over maturity. In addition, the uplift and denudation in the end of Yimin
formation is strong. The tectonic transformation in this period controlled the development range of effective source rocks. According to the above characteristics, it shows that the end of Nantun Formation and the end of Yimin formation are the two key periods of hydrocarbon accumulation in this area. This paper mainly focuses on the top surface of n2 and y2+3 sections to restore basin prototype.

3.3. prototype basin
According to the formation mode of different periods in the faulted basin, the denudation thickness is checked by using seismic stratigraphic trend method, combined with single well acoustic time difference method and vitrinite reflectance method. Prototype basin restoration [5-6] of Hongqi depression shows that there are three sub depressions developed during the fault depression period. Shutenor sub depression is the main subsidence center. Hongqi ranch sub depression is the main subsidence center during the deposition period of Yimin formation. But the uplift and denudation amount of Hongqi ranch sub depression is large. Shutenor sub depression continues to be deeply buried. So its prototype remains good (Fig. 3). During the deposition period of Tamulangou formation, the depression controlling faults began to extend and the volcanic activity was frequent. The development of lake Basin was limited due to the influence of volcanic institutions. During the deposition period of Tongbomiao formation, the depression controlling faults continued to extend and the lake basin developed. But the water body was shallow. During the deposition period of n1 section, the lake basin rapidly stretched and the water body became deeper. During the deposition period of n2 section, the secondary depression controlling faults had the characteristics of local activity and controlled the development of n2 section. Shutenor sub sag was developing continuously. The fault activity of Hongqi ranch and Ganggangtu sub sags were weakened or even inactive. The sedimentary characteristics of the strata in the fault depression period are not obvious. The lake basin shrinks obviously. From the end of n1 section to the end of n2 section, a series of nose like structural zones were formed in the depression. They were the most favorable exploration zone in Hongqi sag. During the deposition period of Damoguaihe formation and Yimin formation, the depression was not controlled by the fault of the depression. It had the characteristics of fault depression transition period. At the end of Yimin formation, another compression and uplift tectonic movement occurred. Hongqi ranch sub depression was eroded strongly. So there is not much left in the remaining Yimin formation.

4. Lithofacies palaeogeography
Through detailed single well dissection, facies analysis, well sequence stratigraphic correlation, geophysical methods and combined with the prototype characteristics of the basin, the sedimentary facies combination and its evolution characteristics are comprehensively analyzed in Hongqi depression. Then restore the lithofacies paleogeographic pattern of different sedimentary periods [7-8].

Drilling in the Tamulangou formation reveals that a set of sedimentary assemblages coexisting with volcanic rocks and sedimentary rocks is mainly developed. The characteristics is two sets of volcanic rocks sandwiched with two sets of sedimentary rocks. The lithofacies paleogeographic pattern
coexisting with volcanic rocks, fan delta and lake is developed (Fig. 4). During the depositional period of Tongbomiao formation, fan delta shallow lake sedimentary assemblage type was developed. Vertically, it is a complete set of sedimentary cycles (Fig. 4). The sedimentary period of the Nantun Formation is similar to that of the Tongbomiao formation in lithofacies and paleogeography. The biggest feature of the Nantun Formation is that the lake basin expanded rapidly. The water body became deeper and the lake basin became larger. The fan delta shrunk. During the deposition period of n2 section, the lake facies was the main sedimentary facies. The fan delta continued to shrink. The sedimentary period of Nantun Formation is fan delta lacustrine sedimentary assemblage (Fig. 4). During the depositional period of Damoguaihe-Yimin formation, the depression is not controlled by the fault. It is a fan delta lacustrine assemblage dominated by lacustrine deposits (Fig.4).

5. Conclusion
Hongqi sag is a dustpan fault depression of single fault with faults in the West and faults in the East. There are three kinds of depression structures. The restoration of prototype basin shows that there are three sub depressions developed in the fault depression period. The Shutenor sub depression is deeply buried. The prototype remains well. In the sedimentary period of Tamulangou formation, the lithofacies palaeogeographic pattern of volcanic rock, fan delta and lake coexisted. In the sedimentary period of Tongbomiao formation, the fan delta shallow lake sedimentary association developed. In the sedimentary period of Nantun Formation, the fan delta lake sedimentary association developed. The sedimentary period of Damoguaihe-Yimin formation is a fan delta lacustrine sedimentary assemblage dominated by lacustrine deposits.

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