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Sedimentary Reservoir Characteristics of Fuyu Oil Formation in the Middle of Fuxin Uplift, Southern Songliao Basin

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Abstract: Currently, the Fuyu reservoir in the middle of the Fuxin uplift, located in the southern Songliao Basin, is in a high water cut development stage. The understanding of this reservoir is limited, and the distribution of favorable reservoirs remains unclear, necessitating detailed reservoir characterization. This study employs a combination of well and seismic technologies to accurately depict the sedimentary and reservoir characteristics of the Fuyu oil reservoir. By conducting detailed correlations of oil zones, a regional high-resolution isochronous stratigraphic framework is established. The division of sedimentary microfacies enables fine characterization of single sand bodies, identifying channel boundaries, clarifying lateral connectivity, and detailing the vertical contact relationships of sand bodies across different deposition periods. The results demonstrate that root-mean-square amplitude and total energy metrics effectively correspond to sand bodies in the study area and can be used to analyze sand body distribution. Provenance is primarily from the southwest to the northeast, with shallow deltas predominantly developed. Delta plain subfacies are found in zones 4-12, while delta front subfacies are in zones 1-3. Microfacies types mainly include the main distributary channel, distributary channel sides, crevasse splay, overbank sand, and underwater distributary channels. The main distributary channel reservoirs exhibit the best physical properties, with porosity ranging from 20-25%, while sand bodies at the sides of distributary channels reach 15-20%. Predicted favorable areas are mainly located at the intersections of distributary channels and structural highs, where drilling is likely to yield high oil flow.

Keywords: Southern Songliao Basin; Fuxin Uplift; Fuyu Reservoir; Distributary Channel.

1. Overview of the Study Area

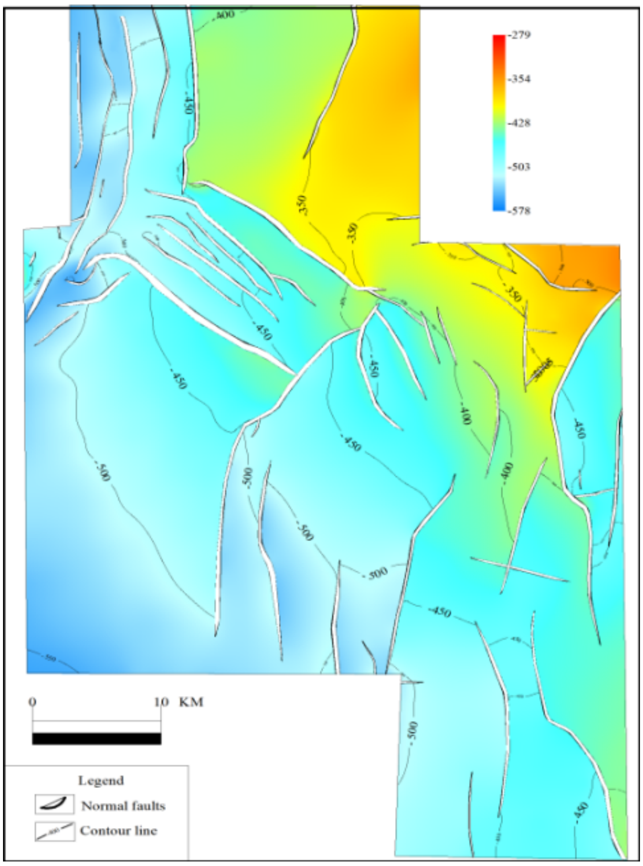

Fig 1. The top surface map of Quantou Formation in the study area

The Fuxin uplift, located in the southern central depression of the Songliao Basin, is a paleouplift oriented in an east-west direction. It comprises the Fuyu I, Fuyu III, Mutou, and Xinli structures from east to west [1-2]. The elevation of the top structural highs of the fourth member of the Quantou Formation gradually decreases from east to west. The faults developed on the Mutou structure are all normal faults, extending in a near north-south direction. These faults are small in scale, with curved extensions on the plane (Fig. 1). The maximum extension length ranges from 2 to 12 km, generally between 3 and 6 km, with fault displacements typically around 20 to 50 meters. Due to faulting, a tectonic pattern of near east-west distribution, resembling a half-graben, has formed.

1.1. Stratigraphy Overview

The target formation of the study area is Fuyu oil reservoir, which is equivalent to the fourth member of Quantou Formation of the Lower Cretaceous, which is conformablely with lower third Member of Quantou Formation and Upper first Member of Qingshan Kou Formation. The formation thickness is 120m-130m. The first member of Qingshan Kou Formation consists of gray black mudstone, silty mudstone and oil shale [3-5]. The second and third members are composed of gray or gray-black mudstone, calcareous siltstone, and ostracoid beds, and are occasionally interspersed with biological limestone. River-delta sedimentary system is developed in Quantou Formation. The first member of Quantou Formation is composed of purple conglomerate, gray sandstone and variegated mudstone. The second member of Quantou Formation is interbedded with purple mudstone and gray white sandstone. The third member of Quantou Formatino is interbedded with grayish white sandstone, purplish red argillaceous siltstone, mudstone with grayish green mudstone and sand conglomerate; The fourth member of Quantou Formation consists of gray silty sandstone, gray-green siltstone mudstone and purplish red mudstone. In this paper, the Fuyu reservoir is divided into four pay zones, which are respectively pay zone IV, pay zone III , pay zone II and pay zoneI from the bottom (Fig.2).

2. Classification of Sedimentary Facies

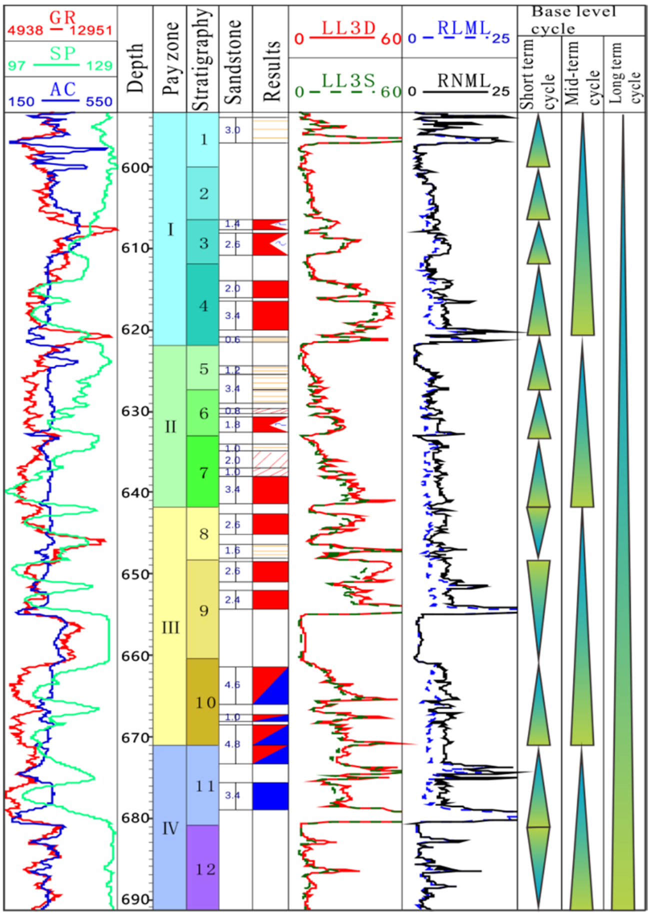

Fig 2. Composite stratigraphic column chart

During the deposition of the Fuyang oil reservoir in the Fuxin uplift, the lacustrine basin in the Songliao Basin expanded continuously, causing the river to retreat. In the middle period, the river flowed through the study area and entered the lake, meandering river point bar sand and delta channel sand deposited. In the late period of the fourth member of the Quantou Formation [4-8], the Xinli area was situated on the flank of the delta distributary plain, resulting in the deposition of poorly developed distributary channel sand. By the end of the fourth member of the Quantou Formation, thin sand deposits of the delta front were widely developed. Alternating deposits of channel and flood occurred both horizontally and vertically, eventually culminating in black mudstone lake deposition. During the early and middle periods of the Fuxin uplift zone, the fourth member of the Quantou Formation represented the lower reaches of a meandering river. In the late period of the fourth member, delta deposits formed. It is concluded that layers 1-3 of the Fuyu reservoir in the study area are delta front subfacies, while layers 4-12 are delta plain subfacies.

2.1. Facies Marker

(1) Delta plain subfacies

The overall sedimentary characteristics are as follows: a. the flood plain is characterized by a thin layer of sand, a thicker layer of purple and variegated mudstone, containing calcium particles and carbonaceous fragment; b. the branch channel is characterized by strong current erosion and traction current deposition; c. the difference between the delta plain subfacies and meandering river facies is that the mudstone in river plain is mainly purple red, but more gray green; The thickness of mudstone monolayer is thinning. Thin layer sand increase; branch channels are relatively developed; the grain size becomes finer; further away from the source.

Table 1. Table of sedimentary facies classification

Facies	Subfacies	Microfacies
Deltas	Deltas plain (Pay zone II, III, IV)	Main distributary channel
		distributary edge
		natural levee
		overbank
		crevasse splay
		crevasse channel
		interdistributary bay
	Deltas front (Pay zone I)	Main distributary channel
		distributary edge
		sand sheet
		distal bar
		mouth bar
		interdistributary bay

1) Distributary channel microfacies

The microfacies of the branch channel has obvious river binary structure and typical positive rhythm. It is mainly silt, the particle size is slightly coarser than the adjacent microfacies, and the cumulative probability curve is two-stage, and the sorting is not good. There are obvious bottom scour structures and large unidirectional flow stratification, and there are few fossils. There are long strips along the river bed. Most of them are associated with highly developed thick blocky stratified purple mudstone[9-12]. It forms the framework of subfacies deposits in the delta plain.

2) Natural levee microfacies

The natural levee microfacies are mainly composed of relatively concentrated small micro-fine cross-bedding, wavy horizontal bedding, argillaceous siltstone facies with thin siltstone or silty mudstone, and appear in the profile in the form of mudstone in the thick flood plain or at the top of the channel deposit. Away from the river bed, the sediment becomes thinner and the mud increases, and various wavy bedding and water ripple marks are common.

3) crevasse splay microfacies

The fracture fan microfacies can form a large area of sheet sand layer, which is finer than the bed deposit. It has reverse rhythm and is dominated by siltstone, argillaceous or calcareous siltstone and over-lithology. It has medium-small cross-bedding or massive bedding, similar to river crevasse splay.

4) flood plain microfacies

The microfacies of the flood plain is dominated by thick layers of purple, variegated, gray-green, gray massive bedding containing calcium particles, carbon chips, wormholes and mudstone with few animal fossils.

(2) delta front subfacies

The overall sedimentary characteristics are as follows: a. the color of mudstone is mainly reduced color such as gray green, with little or no oxidation color; b. with relatively developed lacustrine energy bedding, such as wavy, oblique wave, rhythm, lenticular bedding, corrugation, agitation structure; c. the sandstone is fine lithology, mainly siltstone; d. reducing authigenic mineral; e. there are fossils, such as ostracoda, plant debris or carbon debris; f. the underwater branch channel is thin, narrow, weak erosion.

1) underwater distributary channel edge

There are some channel characteristics such as bottom scour or abrupt surface, positive rhythm and vertical sequence of channel. Different from the delta plain branch channel: a. associated with obvious interdisbutary bay; b. erosion ability weakened; c. thin sand fine grain; d, top mutation;

2) mouth bar

The microdeposits of mouth bar are mainly sorted and pure fine sand with cross-bedding and medium to thick layers, which show an inverse rhythm on the SP logging curve.

3) distal bar

The sediment of the far sand bar is finer than that of the estuarine sand bar, mainly silt, and there is a small amount of mudstone and fine sand, and trough cross-bedding is developed, which is smaller in scale than that of the estuarine sand bar. It shows inverse rhythm on the SP logging curve.

4) front sheet sand

The front sheet sand microfacies is dominated by thin layer siltstone and argillaceous siltstone, with obvious small inverse rhythm or finger shape, with wavy, lenticular and horizontal wavy bedding, top mutations.

Zone IV, III and II mainly consist of distributary channel deposit, with highly developed sand bodies, which are mainly composed of purplish red mudstone, and oil-bearing grades are oil bearing, oil immersed and oil spot. Layer 4 of Zone I are still mainly deposited in distributary channel, the sand body is highly developed, and the oil level is oil bearing, oil immersed and oil spot. The layer 1-3 of the Zone I are mainly composed of underwater distributary channels and sheet sand deposits. The mudstone is gray-green and black, and the oil level is oil immersion, oil spot and oil stain.

2.2. Sedimentary Facies Evolution

(1) Zone IV

Zone IV of 4th member of Quantou Formation consists of layer 12 and layer 11 (Fig.3). From layer 12 to layer 11, the thickness of sand body becomes larger, and the distribution range extends to the center of the northeast lake basin. During the layer 12 deposition period, there were several distributary channels in the southwest with a small development scale, and the maximum width of the main channel was 215m. During the layer 11 deposition period, the provenance of the study area still came from the southwest direction and advanced to the basin along the east and north. There were mainly three distributary channel development zones, and the number and scale of distributary channel development increased, and lateral migration occurred at a certain distance. The channel ability to carry debris has been significantly enhanced, and the channels formed in the middle to northeast of Block 152 intersect into a single piece, with the main width of the channel up to 520m.

(2) Zone III

Zone III consists of layer 10, 9 and 8 (Fig.3). From layer 10 to layer 9, the sandstone in the study area gradually increases in distribution and thickness, indicating that the river energy transporting detrital material in this area increases during this period, which may be caused by the increase of seasonal rainfall. From layer 9 to layer 8, the thickness of sandstone deposition in the study area decreases, and the distribution area of sandstone decreases sharply, indicating that during the deposition period of

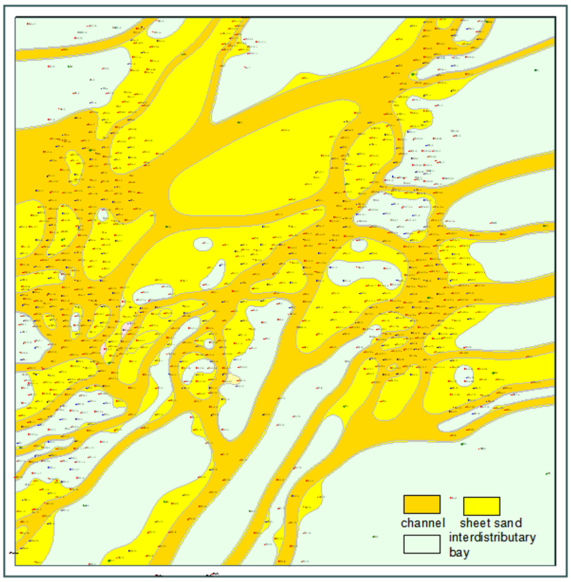

Fig 3. Sedimentary microfacies map of layer 12

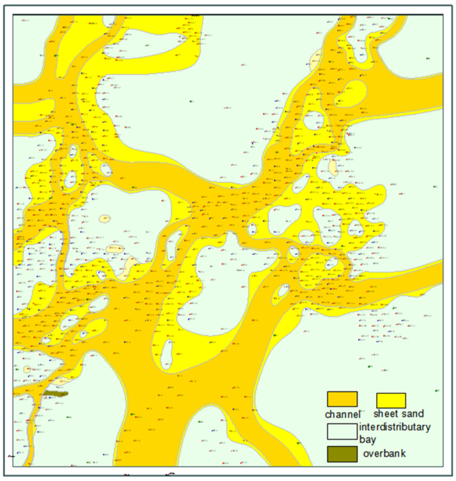

Fig 4. Sedimentary microfacies map of layer 9

layer 8, the amount of detrital sediments transported by the river to this area decreases, and the decrease of the space to accommodate sand body distribution tends to decrease. During the deposition period of layer 9, the source from southwest direction transported into the lacustrine basin along the southern and eastern part of the southeastern area of the nose-structure, and the distributary channels were very developed. Compared with the layer 10, the number and scale of the channels increased to a greater extent, and there were 4 main distributary channels. During this period, the accommodation space of the study area increased, and the detrital material carried by the distributary channel unloaded and accumulated to form a large area of continuous sheet-like channel sand body, accounting for 41.7% of the whole study area. Among them, a large area of continuous channel sand body formed in the middle of the study area from the middle of Block 152 to the middle of Block 147.

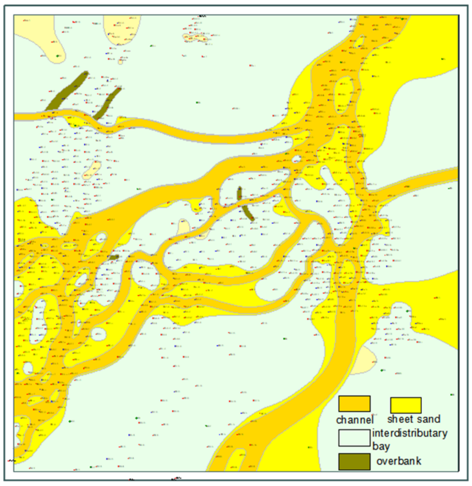

Fig 5. Sedimentary microfacies map of layer 6

(3) Zone II

Zone II consists of layer 7, 6 and 5 (Fig.6). In this deposition period, the study area inherited the sedimentary characteristics of Zone II, the southwest of the study area was enhanced in terms of debris supply capacity, and the sand body had a trend of advancing to the northeast. The southwest of Block 55 was basically stable in terms of debris supply capacity, and the distributary channel was relatively developed, with large sand body thickness and wide distribution range. From the layer 7 to layer 6, the development range of the main sandstone in the study area is reduced, and the thickness is also thinner. However, it can be seen that the debris supply ability of the southwest of Block 152 is weakened, and the distribution range of the sand body in the main channel is reduced. From the layer 6 to the layer 5, the thickness and distribution range of sandstone deposits in the study area decrease sharply. The average thickness of sand bodies is only 2m, and the distributary channel is very underdeveloped, indicating that the flow of distributary channel decreases sharply during this period, and its ability to carry debris is also greatly reduced. In the deposition period of layer 7, the river has the strongest ability to transport debris, the largest development scale, and the width can reach 400m. During the deposition period of layer 6, multiple distributary channels developed, and the main channel width narrowed. During the deposition period of layer 5, the development scale and width (160m) of the channel shrank greatly, and the sand body mainly developed in the northwest side of Block 152 and Block 147.

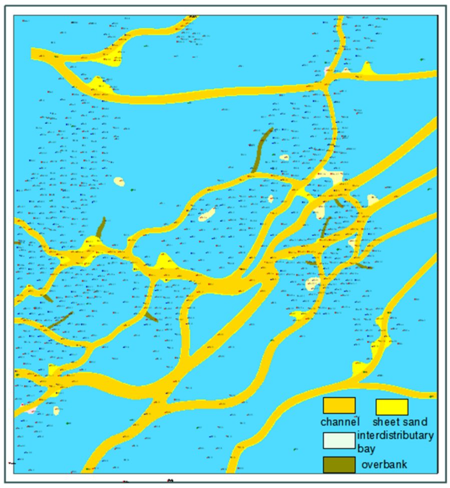

Fig 6. Sedimentary microfacies map of layer 2

(4) Zone I

Zone I consists of layer 4, 3, 2 and 1. In this sedimentary period, the study area was greatly restricted by the regional water inflow conditions, the distributary channel transporting debris gradually shrank, the sand body did not develop, and the size of the sand body formed by sedimentation was greatly reduced compared with that in the Zone II. From layer 4 to layer 1, the distributary channel in the study area extends from land to underwater, the distribution range of sand body decreases sharply, the sand sheet development area is small, and the mouth bar is not developed. Due to the rapid increasing of the lake water depth, the distal bar deposition on the slope of the lake basin did not develop, and the semi-deep lake mud deposition area expanded. On the whole, the 1, 2 and 3 layers of the Zone I are the least developed section in the southeastern area of the nose-structure. The water depth of the lake basin is large, and the gray-green and dark mudstone are very developed.

3. Reservoir Characteristics

Quantou Formation in the study area has shallow burial depth of about 550-800m and weak compaction. The main reservoir of distributary channel has the best physical property, with porosity of 20~25% and sand body of 15~20% at the side of distributary channel. The microfacies mud content in the interdistributary bay is high, the sorting is medium, the surface pore rate is 0.5%-3%, the support type is particle support, and the contact mode between particles is line contact. Due to the shallow burial depth, the compaction effect is weak, and the dissolution effect is strong, the physical property is relatively good. Both primary and secondary pores are developed, of which the primary pores are mainly preserved in the intergranular pores, and the secondary pores are mainly feldspar particle solution pores, intergranular solution pores and mold pores.

4. Conclusion

The comprehensive analysis shows that shallow water delta deposits are mainly developed in the study area, delta plain subfacies in layers 4-12 and delta front subfacies in layers 1-3. The microfacies types mainly include main body of distributary channel, distributary channel edge, crevasse splay, overbank, underwater distributary channel edge, sheet sand, mouth bar, and distal bar.

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