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Sedimentary microfacies characteristics within the high-resolution sequence framework of the Fuyu oil layer in the New North region

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Abstract: The Xinbei Oilfield has gone through decades of exploration and development, and lithological oil and gas reservoirs with stronger concealment are currently the focus of research. It is urgent to implement the sedimentary microfacies and sand body distribution characteristics of the Fuyu oil layer in the Xinbei area, providing a new theoretical basis for predicting the "sweet spot" of facies control in the area. Using core, logging, and logging data from the study area, a high-resolution sequence stratigraphic framework of the Fuyu oil layer was established. The distribution characteristics of sedimentary microfacies within the sequence framework were analyzed. The study showed that the Fuyu oil layer in the study area was divided into one long-term base level cycle of rising half cycle, four medium-term base level cycles, and 13 short-term base level cycles; In the area, river controlled shallow water delta plains and front sediments are developed, and a total of 10 types of sedimentary microfacies have been identified. Among them, the (underwater) distributary channel sand body, as the dominant reservoir sand body, extends along the southwest to northeast direction. As the A/S value increases, four stacking styles are developed vertically, including vertical shear stacking, staggered shear stacking, horizontal shear stacking, and isolated distribution. In the horizontal, the locally developed wide channel sand body composite zone gradually transitions into a single channel.

Keywords: Songliao Basin; Fuyu oil layer; Shallow water delta; High-resolution sequence stratigraphy.

1. Introduction

Fuyu oil layer in Fuxin uplift belt of Songliao Basin is one of the key areas of exploration and development in southern Songliao. For many years, geologists have carried out a lot of research work on stratigraphic division, correlation and sedimentary characteristics of this area based on sequence stratigraphy and sedimentology theory, but there are great differences between the research conclusions of different students. In the research of sequence stratigraphy, different scholars hold different theoretical viewpoints, use different data and focus of research, which leads to the disunity of sequence stratigraphic division and correlation scheme of Fuyu oil layer in Songliao Basin. For example, Zhang Qingguo and others[1] divided the third and fourth members of Quan in Fuyu Oilfield into a third-order sequence, and the fourth member of Quan in Fuyu oil layer is divided into four fourth-order sequences and thirteen fifth order sequences; Sun Yu and others[2] believe that the Fuyu oil layer in the southern Quan-4 section of the Fuxin Uplift Belt is an upward half cycle of a long-term base level cycle, which is internally divided into four medium-term base level cycles and thirteen short-term base level cycles; Xue Chunqi and others[3] divided the Fu I oil layer formation (Quan 4 member) in the Toutai area into an ascending half cycle of a long-term base level cycle, three mid-term cycles, and seven short-term cycles. In addition, there are also differences on the understanding of the sedimentary system of Fuyu oil layer in the fourth member of Quan Formation. Chen Shaojun and others[4] believe that the fourth member of Songnan Quan Formation generally develops alluvial fan river sedimentary system; Zhang Xin[5] believes that the fourth member of Songnanquan has developed a sedimentary system of "braided river meandering river terminal fan" as a whole. From the perspective of geography and structural location, the Xinbei area has developed terminal fan deposits correspondingly; Sun Yu and others[6] and Luo Chao and others[7] both believe that the southern and eastern margins of the Fuxin Uplift in the Songliao Basin have developed branched shallow water deltas in the Fuyu oil layer of the Quansi Formation. From this, it can be seen that the Fuyu oil layer in the New North region is still unclear in terms of sequence stratigraphic division and facies types.

Guided by sedimentology, reservoir geology and high-resolution sequence stratigraphy theory[8]-[10], combined with a large number of previous research results, and comprehensively using detailed core, logging and logging information, this study divides Fuyu oil layer into four medium-term base level cycles (MSC1-MSC4) and 13 long-term base level cycles (SSC1-SSC13, The thin well area is predicted based on the remote sand body composite pattern, and the plane distribution of microfacies in each short-term base level cycle sedimentary period in the study area is finely depicted, which deepens the research and understanding of the sedimentary system, microfacies types, and vertical and horizontal distribution laws of sand bodies of Fuyu oil layer in the New North area, and provides a solid geological foundation for the research work such as the optimization of favorable production target areas.

2. Geological Overview

The geographical location of the Xinbei area is in Balang Township, Songyuan, Jilin Province. The structural location is on the western slope of the northern part of the Fuxin Uplift Belt, and the northern tip of the Xinli Xinbei large-scale nose shaped structure. The total area of the research area is about 116m2, with a total of 260 drilling wells and uneven distribution of well networks. The research horizon is the Fuyu oil layer in the Quansi section, with a thickness of about 113-157m. Under sedimentary conditions such as flat terrain,

stable structure, dry climate, and oxidation environment, it is affected by the Southwest Baokang Controlled by two major source systems in Southeast Huaide, the sand body framework dominated by large river controlled shallow water delta deposits is generally developed. Oil and gas mainly come from the northern and western areas of the Source rock of the first member of the overlying Qingshankou Formation, which is a typical reservoir forming model of "upper generation and lower reservoir".

3. Types and characteristics of sedimentary microfacies

By analyzing the logging curves of 31 exploration and evaluation wells and 229 development wells in the New North region, as well as some core and logging data, combined with previous research results, it is concluded that the sedimentary period of the Fuyu oil layer in the area is mainly controlled by the river controlled shallow water delta sedimentary system of the Southwest Baokang source. Furthermore, it is divided into delta plain and delta front subfacies, with a total of 10 microfacies identified (Fig. 1).

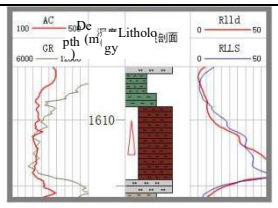
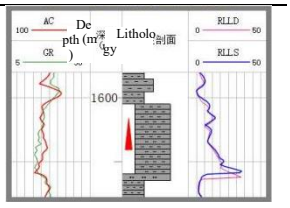
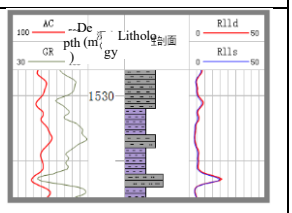
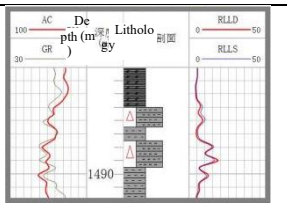
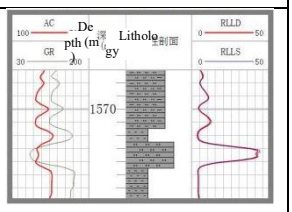
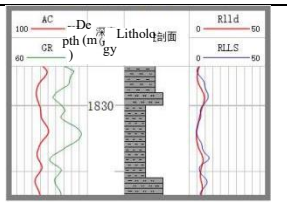
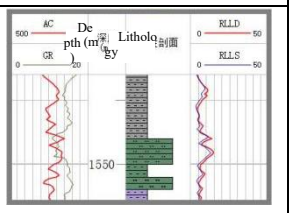
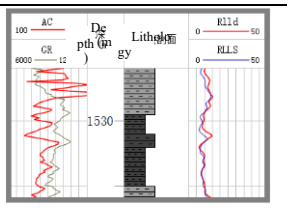
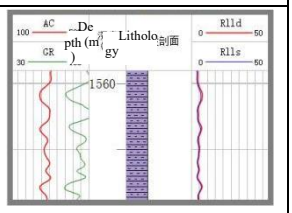
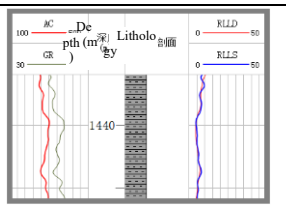
Subphase	Microfacies type	Logging microfacies	Subphase	Microfacies type	Logging microfacies
Delt plain	Distributarchannel		Delta front	Underwater Distributary channel	
	Abandoned River channels			Sheeted sand	
	Overbank sand			Inner edge of mat	
	Natural embankment			Outer edge of seat	
	Shunt room			Underwater Diversion room	

Fig. 1 Sedimentary microfacies types and characteristics of Fuyu oil layer in the research area

3.1. Delta plain subfacies

The distributary channel is the main microfacies type in the delta plain deposits. The lithology is mainly grayish white, gray or dark gray fine and siltstone. There is an obvious scouring surface at the bottom, and the grain size becomes finer upward. The bedding types are diverse, mainly blocky, staggered, wavy and horizontal bedding, which can be subdivided into three categories. The scale of the sand bodies of the distributary channel from Class I to Class III decreases successively The physical properties of the reservoir increase and decrease in sequence: 1) A type of distributary channel: thick box shaped or thick bell box composite shaped with extremely high to high amplitude difference, with sandstone thickness often exceeding 8m; 2) Class II distributary channel: typical box or bell shaped with high amplitude difference, with sandstone thickness ranging from about 5-8m; 3) Three types of distributary channels: micro toothed or toothed bell shaped with medium to high amplitude difference, and sandstone thickness is basically less than 5m. The vertical sedimentary sequence of abandoned river channels presents a "dichotomy" phenomenon, which is manifested from bottom to top as early distributary channel sedimentation and overbank sedimentation after cutting and straightening. The

logging curve morphology corresponds to a bell shaped and serrated shape with high to medium amplitude difference or a relatively smooth straight shape, and the thickness of sandstone is about 2-4m. Overflow sand deposits are not well developed in the study area. The lithologic structure is characterized by small cross bedding or block bedding of siltstone and argillaceous siltstone. The bottom is a lithologic mutation surface, usually less than 2m thick. The logging curve shows a finger shape of medium low amplitude difference. The natural levee is close to both sides of the distributary channel and distributed in strips. The natural levee at the concave bank is not easy to be retained. The convex bank is located on the top sediment of the edge beach, which is difficult to be divided separately. The lithology is mostly siltstone, argillaceous siltstone and mudstone interbedding. Biofossil traces are occasionally seen. The shape of the logging curve is box shaped or finger shaped with low amplitude tooth. The lithological structure between the distributaries is characterized by purple red, grayish green, variegated, and gray block layered mudstone, with visible carbonization and rooting, calcium particles, and biological drilling. The sedimentary thickness is relatively large, ranging from a few meters to tens of meters, and the electrical characteristics are extremely low to low amplitude smooth or interbedded with flat and protruding straight lines.

3.2. Delta front subfacies

Compared with the onshore distributary channel deposition, the underwater distributary channel swing is more restricted, the sand body thickness is thinner, about 2-5m, the water system energy is reduced, the sediment grain size is smaller, and the bottom is not developed with obvious small scouring surface or relatively straight lithologic mutation surface. The lithologic characteristics are mainly brown, grayish green, gray siltstone, argillaceous siltstone. The more affected by the lake energy, the narrower the underwater distributary channel is until pinch out occurs, divide them into two categories: 1) One type of underwater distributary channel: typical box or bell shaped with high amplitude difference, and sandstone thickness greater than 4m; 2) Class II underwater distributary channel: micro toothed or toothed bell shaped with medium amplitude difference, with a thickness of about 2-4m. The sheet sand deposition is formed by the transformation of the underwater distributary channel by lake water or the overflow of the bank in flood period, so it can be distributed in the front of the end of the channel in a flower shape, or distributed on both sides of the channel in a strip shape. The lithologic structure is mainly grayish green, gray wavy bedding, massive bedding siltstone, argillaceous siltstone, and there are calcareous intercalations in some parts. The shape of the logging curve is medium amplitude finger shaped, flat toothed bell shaped, and flat funnel shaped, the thickness is about 2m. The lake water remoulds the sheet sand again, and gradually forms deposits at the inner edge and outer edge of the sheet according to the energy decreasing around. The lithologic structure is shown as gray thin layer argillaceous siltstone and silty mudstone with lake energy bedding, and the logging curve shape is shown as low amplitude finger shape, extremely flat funnel shape or bell shape. The underwater interdistributary sedimentation is in a weak reduction environment, and the mudstone is mainly in primary color. The lithologic structure is shown as grayish green, gray, black massive bedding mudstone, occasionally mixed with a small amount of thin silty mudstone, and pyrite can be seen locally. The logging curve shape is shown as very low low amplitude micro teeth or smooth straight shape.

4. Establishment of high-resolution sequence framework

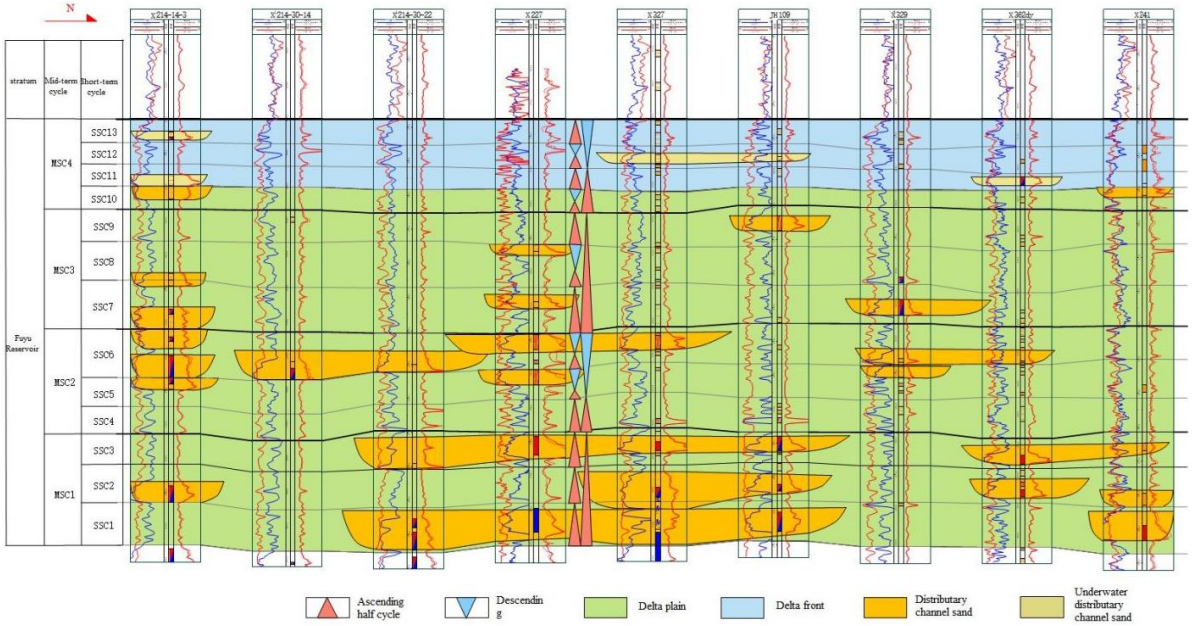


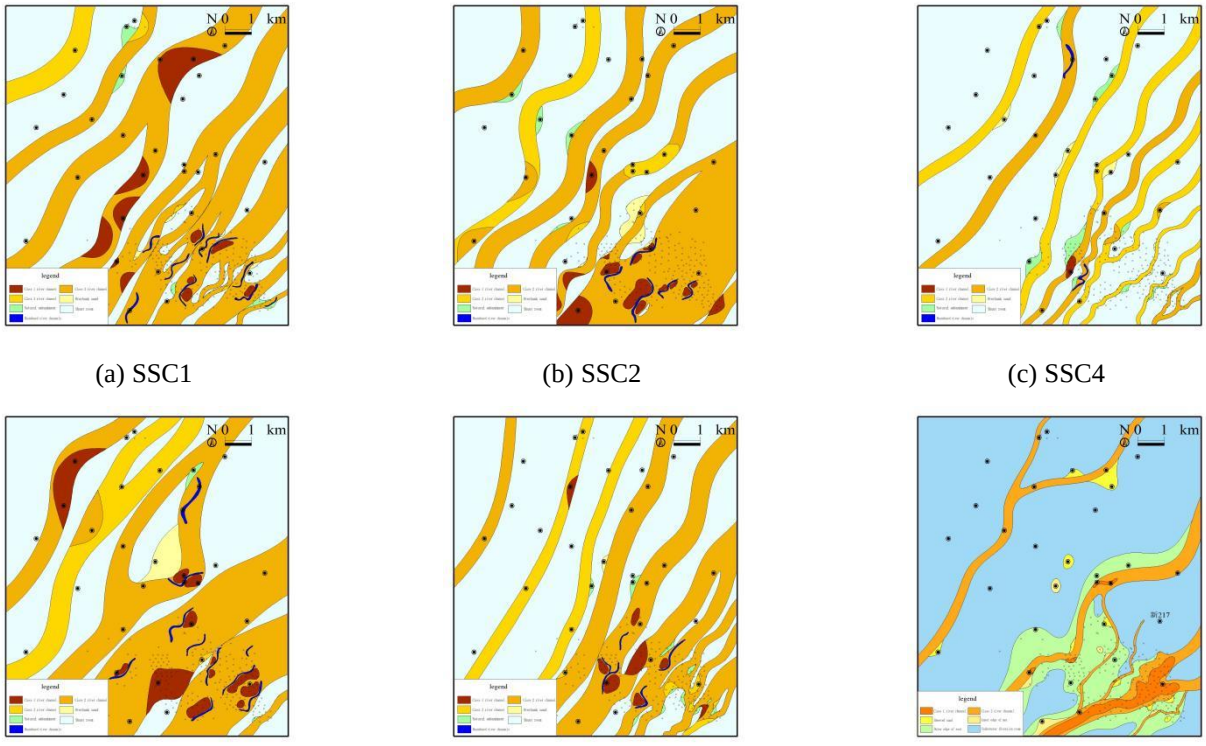
Figure 2. High Resolution Sequence Stratigraphic Connected Well Profile of Fuyu Reservoir in the Study Area

Using core, logging, and logging data, identify the characteristics of different levels of base level cycle interfaces within the Fuyu oil layer, and establish a high-resolution sequence stratigraphic framework for the entire region based on short-term base level cycles. Divide the Fuyu oil layer in the New North region into 4 mid-term base level cycles and 13 short-term base level cycles. Selecting a connected well skeleton profile in the direction of near parallel material sources for sequence stratigraphic comparison and sand body distribution characterization can more intuitively reveal key geological features such as stratigraphic thickness, stratigraphic stacking style, and sand body geometry in the study area. From the stratigraphic comparison results of the connected well profile (Fig. 2), it can be seen that the overall

thickness of the Fuyu oil layer in the New North region is characterized by "slightly thicker at both ends and slightly thinner in the middle". This area is mainly controlled by the Southwest Baokang source, and the trend of the distributary channel sand body is in a southwest northeast direction. The structural terrain is relatively flat, and the overall change in stratigraphic thickness is not significant. The top and bottom interfaces of the Fuyu oil layer are stable vertically, and are affected by changes in A/S values, the southwest part of the study area adjacent to the source of matter developed and overlaid distributary channel sand bodies during the MSC1 and MSC2 sedimentary periods. The downcutting effect of the distributary channel caused the sequence boundary of the mid-term base level cycle to move downwards, reducing the scale of the northeast river channel, thinning the thickness of the sand body, mainly due to vertical aggradation, and poor stratigraphic preservation. The short-term base level cycle was mainly an asymmetric cycle (A1) that deepened upwards, with few types of sedimentary microfacies, the reservoir has good physical properties and a wide distribution of oil layers, making it a key reservoir system in the New North region; During the MSC3 sedimentary period, the short-term base level cycle gradually transformed from an asymmetric cycle that became deeper upwards to a symmetric cycle that became deeper upwards and shallower again (A2, C). The phenomenon of sand body displacement and lateral shear stacking in distributary channels was more obvious, mainly due to lateral aggradation, and the reservoir properties deteriorated; During the MSC4 sedimentary period, it was in a relatively low energy sedimentary environment, and the short-term base level cycle structure style was complex (A2, B2, C). The underwater distributary channel sand bodies were isolated and dispersed, mainly due to filling and deposition, and were constrained by both lake flow and river flow. Thick layers of muddy sediment formed local cover or interlayer.

5. Characteristics of sedimentary microfacies within a high-resolution sequence framework

Under the control of a high-resolution sequence stratigraphic framework, a planar distribution map of sedimentary microfacies in the Fuyu oil layer in the New North region was drawn. During the SSC1-SSC10 period, delta plain sedimentation was developed, while during the SSC11-SSC13 period, delta front was developed. Several representative short-term base level cycles were selected for detailed description.



(a) SSC1 (b) SSC2 (c) SSC4

(d) SSC6 (e) SSC7 (f) SSC11

Fig. 3 Sedimentary microfacies map of short-term base level cycles

(1) Plane distribution of SSC1 and SSC2 sedimentary microfacies

The sedimentation period of MSC1 was in the early stage when the long-term base level dropped to the lowest point and then slowly rose. As a whole, it belonged to the sedimentary environment of high-energy river controlled shallow water delta plain, with sufficient source supply and strong hydrodynamic force. The lithology was dominated by fine sandstone, siltstone, and mudstone. The mudstone color was mostly purple, purplish red, and variegated, and gray green was rare. The short-term base level cycle development was dominated by the asymmetric (A1, A2) cycle style of deepening upward, Contains three short-term base level cycles. During the SSC1 sedimentation period, the A/S value was small, the river action potential was strong, and medium to large distributary channel sand bodies were developed, with severe vertical shear stacking. Overflow sand and natural embankment sedimentation were not well developed, and the thickness of sandstone was generally greater than 5 meters, with local areas reaching up to 11.8 meters (Fig. 3a); During the SSC2 sedimentation period, the energy of the water system in the southeast region was significantly enhanced,

and a wide composite zone of distributary channel sand bodies was developed, with a maximum width of about 4600m. The plane was severely overlaid, making it difficult to distinguish a single channel. Overall, the thickness of sandstone was generally greater than 4.5m, and locally it could reach as high as 9.4m (Fig. 3b).

(2) Plane distribution of SSC4 and SSC6 sedimentary microfacies

The sedimentation period of MSC2 was in the middle and early stage when the long-term base level accelerated to rise and then the short-term base level dropped. The whole MSC2 belonged to the sedimentary environment of the shallow water delta plain controlled by the Zhongneng River. The lithology was mainly siltstone and mudstone, and the mudstone color was mostly variegated and grayish green, occasionally dark gray. The short-term base level cycle was mainly developed in an upward deepening asymmetric (A2) cycle style, including three short-term base level cycles. During the SSC4 sedimentation period, the reference level rapidly rose and the A/S value increased, resulting in a significant decrease in the energy of the entire water system in the study area. The sand bodies of the distributary channels were small and narrow in shape, and the three types of distributary channels and overflow deposits were relatively developed. The thickness of the sand bodies was generally between 2-5m, with a maximum of 7.1m (Fig. 3c). During the SSC6 sedimentation period, the reference level continued to decline, and the total distribution area of the first type of distributary channel sand bodies significantly increased, with the middle and A wide distributary channel sand body composite belt is developed in the southeast, with the widest part of about 2900m. The reservoir physical property is good, and there are two sand body composite modes of dislocation and transverse cutting. Due to the frequent swing and channel change of the distributary channel, it is difficult to retain the overflow deposit, and the sand body thickness is generally between 4.5-9m, up to 12.4m (Fig. 3d).

(3) Plane distribution of SSC7 sedimentary microfacies

MSC3 sedimentary period is in the middle and late stage of long-term steady rise of base level, which is generally a low-energy river controlled shallow water delta plain sedimentary environment with reduced material supply and weakened hydrodynamic force. The lithology is dominated by argillaceous siltstone, silty mudstone, and mudstone. The mudstone color is mostly grayish green and black, and purple red is rare. The short-term base level cycle development is dominated by asymmetric cycles (A2) and symmetric cycles (C) that become deeper upward, It includes three short-term benchmark cycles. During the sedimentation period of SSC7, the water body deepened compared to the SSC6 period. The width of the distributary channel in the central and southeastern regions was relatively large, with the widest point being about 1500m. It was distributed along the natural embankment or in the form of water droplets on the plane inside the distributary channel. In the northwest region, there were two single distributary channels distributed on the plane, with isolated distribution on the profile. The sand thickness in the entire area was generally between 4-8m (Fig. 3e).

(4) Plane distribution of SSC11 sedimentary microfacies

MSC4 sedimentation period is in the late stage of long-term accelerated base level rise followed by a short decline and then a steady rise. SSC10 period is in the transition period of the front edge of the delta plain. SSC11-SSC13 period belongs to the low-energy river controlled shallow water delta front sedimentation. The lithology is mainly argillaceous siltstone, silty mudstone and mudstone, with a small amount of siltstone sandwiched between them. The color of mudstone is mostly gray and black, During the sedimentation period of SSC11, the base level slightly decreased, the A/S value decreased, and sediment supply increased. The main water system moved towards the southeast, mainly in the form of underwater distributary channel river-controlled sheet shaped sand blob and leaf shaped pattern. Wide sheet edge sedimentation can be seen at the edge of the underwater distributary channel. The widest part of the underwater distributary channel sand body distributed along the Ji58-13 well line can reach 1500m, and its reservoir physical and oil properties are good, with great potential, The thickness of the sand body is mostly 3-4. 5m (Fig. 3f).

6. Conclusion

Based on the theory of high-resolution sequence stratigraphy, combined with core, logging and logging data, the boundary of different levels of base level cycles is defined, and Fuyu oil layer in Xinbei area of Songliao basin is divided into 1 long-term base level cycle, 4 medium-term base level cycles, and 13 short-term base level cycles. The short-term benchmark changes from asymmetric cycles (A) to symmetric cycles (C) and then reverts to asymmetric cycles (A2, B2).

During the sedimentary period of the Fuyu oil layer in the research area, 2 subfacies (delta plain and front edge) were developed, 10 microfacies (distributary channels, overbank sand, natural embankments, abandoned channels, distributary channels, underwater distributary channels, sheet shaped sand, inner edge of the sheet, and outer edge of the sheet), and 4 stacking styles of channel sand bodies were developed. From bottom to top, they were vertical shear stacking, staggered shear stacking, lateral shear stacking, and isolated distribution, At the bottom of the Fuyu oil layer, multiple stage channel sand bodies are commonly cut and stacked with each other. The scale of distributary channels and sand to land ratio are large, gradually transitioning upwards into single stage channels. (Underwater) distributary channels form the framework of sand bodies within the sequence framework and serve as the main dominant facies belt.

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