High resolution Sequence Stratigraphy of Baikouquan Formation in Mahu Sag, the Junggar Basin

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Abstract. Baikouquan Formation of Lower Triassic in Mahu Sag of the Junggar Basin is one of the main reservoirs in the basin, and typical large lacustrine fan delta deposits are developed. This study is based on core observations of the western slope of the Mahu Depression. Through logging, logging, seismic and other data, and applying the principle of high-resolution sequence stratigraphy baseline cycles, a systematic analysis was conducted on the cyclic interfaces of the Baikouquan Formation at all levels on the western slope of the Mahu Depression. The research results indicate that: 1. The bottom of the Baikouquan Formation is in angular unconformity contact with the underlying Urhe Formation. The Baikouquan Formation is generally an upward deepening asymmetric cycle with a long-term base level rise, including the early stage of slow base level rise, the middle stage of continuous base level rise, and the late stage of rising to near symmetric cycle. These three stages have successively developed the sedimentary facies of the front edge of the shallow water fan delta with a retrogressive style The sedimentary facies of the outer front of the fan delta and the sedimentary facies of the front fan delta. The Baikouquan Formation as a whole is a set of retrogradational stratigraphic styles, with the bottom being the water retreat pole and the baseline being in an overall upward process. In terms of sedimentary facies, it gradually transitions from the front edge of the fan delta to the front fan delta, and vertically (from bottom to top), it goes from underwater distributary channels to front edge sheet sand and then to front fan delta mud (T1b3). The above conclusion provides a geological basis for the exploration and development of rich hydrocarbon depressions in Mahu Depression and other similar complex superimposed basins.

Keywords: High resolution sequence stratigraphy; Fan delta; Baikouquan Formation; Mahu Sag; Datum level cycle.

1. Introduction

Mahu Sag in the Junggar Basin has developed the world's largest conglomerate oil field with reserves of 1 billion tons, and has become the most important production base of crude oil in China[1,2]. For this new type of tight glutenite reservoir in the sag, there are outstanding development geological problems, and the traditional theory of sequence stratigraphy can no longer meet the needs of petroleum geological exploration and development. High resolution sequence stratigraphy and its related technical methods have been widely applied in the analysis of complex and variable terrestrial oil and gas basins in China in recent years. This theory is based on the dynamics of stratigraphic sedimentary response and the direct driving mechanism of baseline cycle changes. It has good practicality for analyzing terrestrial fault basins with rapid climate change, frequent tectonic movements, accommodating space, and fast A/S changes[3-5].

The precise division of stratigraphic sedimentary time units and the comparison of overall stratigraphic sedimentary systems are the most fundamental and crucial work in the study of planar sedimentary microfacies, and directly play a crucial role in the precision and accuracy of oil layer research and understanding. Its reliability directly determines the accuracy of oil layer research and understanding, especially the accuracy of oil layer plane and spatial characteristics. Its accuracy directly affects: ① the distribution of planar microfacies and single sand bodies in time units; ② Reservoir connectivity; ③ Differentiation of sand bodies in similar layers; ④ Differentiation of superimposed sand bodies; ⑤Planar heterogeneity; ⑥Fault identification[7,8].

By establishing a high-resolution sequence stratigraphic framework, it is possible to make fine divisions of each horizon and determine the sequence relationships between different horizons.To this end, this article systematically analyzes the high-resolution sequence stratigraphy characteristics of the Baikouquan Formation in the Mahu

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Depression, analyzes the stratigraphic characteristics of the study area, summarizes the facies sequences and reservoir characteristics, and provides a reference for the subsequent exploration and development of the Mahu Depression and other similar complex superimposed basins with rich hydrocarbon deposits.

2. Geological Setting

2.1 Geological Location, Tectonics, and Stratigraphy

Junggar basin is a large intracontinental superimposed basin formed in Northern Xinjiang since Permian[9]. It was a rift basin in the early Permian, a thermal cooling extensional depression in the Late Permian, and a cratonic basin from Triassic to Eogene[10,11]. Since Neogene, an intracontinental foreland basin has been formed due to the collision between the Indian plate and the Asian continent[12]. The study shows that the tectonic evolution of Mahu sag is closely related to the development of the West Junggar Orogenic Belt[13,14]. In the early Permian, the West Junggar fold belt was strongly uplifted and thrust napped to the Junggar block, forming a large foreland basin near the front of the orogenic belt and the suture zone of the block. Its front edge is located in the present Mahu sag, and the basin depression uplift pattern has begun to take shape[15-17]. In the late Early Permian, the tectonic movement was relatively weakened, inherited the previous tectonic pattern, and the subsidence center migrated eastward. The depression and uplift pattern in the basin was basically filled up, forming a unified sedimentary basement. The early Indosinian movement raised the basin as a whole, then evenly subsided, and uniformly accepted Triassic sedimentation. The uplift and compression effect was not obvious. The tectonic activities in and around the basin were relatively calm, with continuous sedimentation and complete sequence. During Jurassic, the basin inherited the Triassic tectonic framework, continued to subside evenly, and the tectonic activity was relatively weak. In the middle and late Jurassic, affected by the collapse of Indosinian orogeny, the area was in an extensional tectonic setting, and the basement of the basin subsided as a whole(Figure 1a,b).

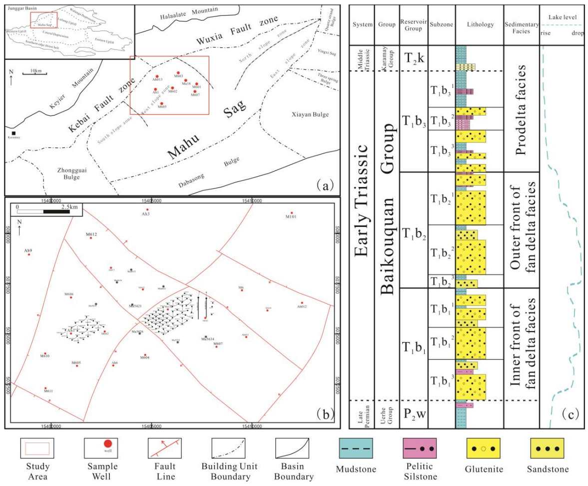

Figure 1. Structural location, well location and comprehensive stratigraphic histogram of Mahu sag. (a)Structural location map of Mahu sag(according to [10],revised); (b)Well location map of study area (provided by Xinjiang Petroleum Exploration Research Institute); (c)Comprehensive geological histogram of Baikouquan formation in the study area.

2.2 Stratigraphy and Sedimentary Environment

The metamorphic basement in Junggar basin was formed in Precambrian, and sedimentation began in Late Carboniferous, which is represented by a set of volcanic and clastic rock sequences developed in the paleoresidual ocean basin. Subsequently, due to the eastward thrust of the western Junggar Orogenic Belt and the uplift of the southern Tianshan Mountains, the whole basin gradually developed into two independent foreland basins; In the early Permian, the foreland "uplift depression" pattern in the northwest margin of the basin has begun to take shape, and a set of volcanic rocks and underwater fan and fan delta facies clastic rocks with huge thickness have been developed in the west depression of Mahu basin 1 well. In the middle Late Permian, the collision, compression and nappe of the northwestern margin of the basin intensified. Especially in the Late Permian, the late Hercynian movement made the northwestern margin of the basin strongly uplifted, and the compression and thrust reached a climax. The thrust belt overthrust the sediments of the foreland depression.

From Triassic to Middle Jurassic, the nappe in the northwest margin developed in succession, forming a series of structural combinations such as thrust, fold, unconformity and overlap, but the intensity of overthrust activity weakened and the fault plane became steeper. In the Early Triassic, the fold mountains on the margin of Junggar basin thrust and napped towards the center of the basin; The Kebai Wuxia fault zone in the northwestern margin of the basin inherited and developed on the basis of the Late Permian, resulting in the subsidence of the north and West slopes of the dehu sag, and the development of a huge area of coarse clastic rock or basal conglomerate dominated by conglomerate, which overlapped the boundary uplift formed by the late Hercynian thrust. From Late Jurassic to Cretaceous, the nappe in the northwest margin basically stopped moving, and the basin entered a shock development stage of

overall subsidence uplift. From Oligocene to Quaternary, affected by Himalayan movement, Junggar basin became a developed foreland basin, while sedimentation in the north and West slopes of Mahu sag basically stopped after Cretaceous.
Interventionary studies involving animals or humans, and other studies that require ethical approval, must list the authority that provided approval and the corresponding ethical approval code(Figure 1c).

3. Materials and Methods

A total of dense well pattern data of well block Ma 18 and adjacent well block Aihu 1 in the west slope of Mahu depression were obtained, including logging curve data (a total of 115 wells with a total length of 18400m and a data point interval of 0.125m), core observation data (a total of 6 wells with a total length of 954.2m), cast thin sections (a total of 107 wells in 4 wells). The seismic data of well block Ma 18 in the study area include 3D seismic data of well block Ma 6 and 3D seismic data of well block Ma Xi 1. The 3D seismic bin of well block Ma 6 is 50m×100m, 30 times of coverage, with a full coverage area of 766.9km^2; 3D seismic bin in Maxi 1 well block 12.5m×12.5m, 280 times of coverage, 398.0km^2 of full coverage. By reprocessing the Triassic 3D seismic data, the continuity of the Triassic internal seismic wave group has been improved, and the resolution and signal-to-noise ratio have been improved to some extent, which can meet the requirements of structural interpretation and lithologic body identification. All the above data are provided by China Xinjiang Oilfield Development Research Institute.
The main content of this high-resolution sequence stratigraphy study is to recognize sequence characteristics through sequence boundary identification, sequence division and order determination based on drilling, outcrop, logging and high-resolution 3D seismic data, and finally establish a high-resolution sequence isochronous stratigraphic framework with multi-level base level cycles as the reference plane. Based on the study of high-resolution sequence stratigraphy of Baikouquan formation in Mahu depression, this paper discusses the control of the development characteristics of Baikouquan formation and the changes of sequence base level cycles on the facies sequence and reservoir.

4. Results

4.1 Sequence boundary identification

Based on the theoretical core of high-resolution sequence stratigraphy, the key to establish a high-resolution sequence stratigraphic framework is to identify the sequence structure types, stacking patterns controlled by base level cycles and their relationship with sedimentary dynamics.

4.1.1 Long term cycle types and characteristics

The long-term cycle is mainly composed of sedimentary filling sequences formed in the process of secondary tectonic activities in the tectonic evolution stage of the basin. The top and bottom boundaries correspond to the strong and weak change surfaces of episodic tectonic activities, which are usually shown as tectonic unconformity or large-scale scouring surfaces formed by local tectonic uplift. The bottom of the Baikouquan formation in the study area is in angular unconformity contact with the underlying Urho formation. The Baikouquan formation is generally an upward deepening asymmetric cycle of long-term base level rise, including the early stage of slow base level rise in the Baikouquan formation, the middle stage of continuous base level rise, and the late stage of rise to the near symmetric cycle. These three stages successively developed the sedimentary facies of the inner front of the nappe shallow water fan delta Fan delta outer front sedimentary facies, front fan delta sedimentary facies.

4.1.2 Mid term cycle types and characteristics

The middle-term cycle is composed of sedimentary filling sequences formed in the process of cold and warm climate changes caused by long-term eccentricity. The time limit is relatively consistent. The top and bottom interfaces should be intermittent exposed surfaces or large-scale secondary scouring surfaces, which have excellent isochronism and comparability in the same secondary basin and sedimentary system.
The depositional period of MSC_1 mainly corresponds to the sand formation of T_1b_1 member divided by predecessors. It was formed in the early stage of long-term base level rise. At this time, the lake level is low, the base level rises slowly, and the sequence bottom interface is a scouring surface. The sediment supply is sufficient, the water flow energy is strong, and the sand body grain size is coarse, which shows that the multi-stage channel sand bodies are superimposed continuously, and the formation reservoir is good, which may become a good oil and gas reservoir.
The MSC_2 sedimentation period mainly corresponds to T_1b_2 member sand formation divided by predecessors. During this period, the accommodation space continued to increase. With the increasing lake transgression, the lake level continued to rise, the flow energy weakened, and the fine-grained sediments began to increase. The formation gradually transited from the continuous overlapping development of multi-phase channel sand bodies to the single-phase contact development. The muddy barrier is relatively developed and has strong shielding ability, which may become a local shielding layer.
The MSC_3 sedimentary period mainly corresponds to T_1b_3 member sand formation divided by predecessors. During this period, the lake transgression scope continued to increase, the lake shoreline rose to the highest point, the sand body thickness became smaller, distributed in an isolated manner, the sediment grain size became significantly finer, the middle and upper compartments of the sequence were relatively developed, there were symmetrical short-term cycles, and the far bar sand body

deposition could be seen on the stratum, which might become a local cap rock or barrier layer.

4.1.3 Short term cycle types and characteristics

Short term cycles are mainly composed of sedimentary filling sequences formed in the process of climate drought and humidity change caused by short cycle eccentricity. They are generally formed by the combination of multiple ultra short term cycles with genetic connection, and have good comparability and isochronity in the same sedimentary system. The top and bottom interfaces correspond to intermittent exposed surfaces, small scouring surfaces and non sedimentary discontinuities. Short term cycles control the sedimentary microfacies sequence, combination characteristics Occurrence type and reservoir heterogeneity. Three types of short-term cycles are identified in the study area: upward "deepening" asymmetric cycle; Upward "shallowing" asymmetric cycle; Symmetrical cycle.

（1）Upward "deepening" asymmetric cycle

There are two types of sedimentary evolution in this type. The first is formed when the accommodation space is small (Figure 2), at this time, the ratio of the growth rate of accommodation space to the sediment recharge flux is far less than 1 (a/s≤1). In the sequence, only the sedimentary records formed by the base level rising half cycle are preserved. The upward falling half cycle makes the sediments unable to be preserved due to erosion and scouring. It is mainly composed of scouring surface or sedimentary discontinuity. This type is mainly developed in the bottom of Baikouquan formation. The sequence is mainly composed of single or multiple mutually incised and overlapped distributary channel sandbodies representing the deposition in the early and middle stages of base level rise. The distributary channel has strong hydrodynamic force, and the sandbodies are seriously overlapped. The lithology is mainly brown sandy conglomerate, and gray and brownish gray argillaceous conglomerate can be seen. The lithology is dense, and mainly massive bedding can be seen. The scouring surface can be seen at the bottom, and the curve toothing is obvious.

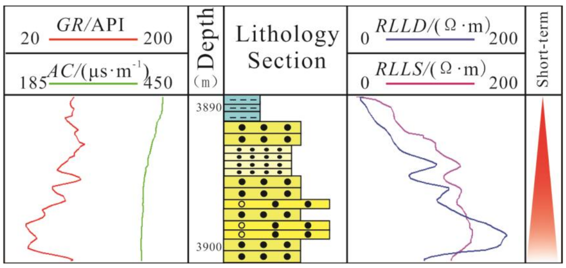

Figure 2. Upward "deepening" asymmetric short-term cycle,Low accommodation(Ma18,$T_1b_1^1$)

When the accommodation space increases and a/s≤1 changes to a/s<1, the sedimentary development formed by the base level rise half cycle is relatively complete (Figure 3). This type is mainly developed in T_1b_2 and T_1b_3 members. At this time, the lake level rises, the rate of increase in accommodation space is less than the rate of sediment supply, and the sand bodies in the off land direction are preserved completely. A weak scouring surface can be seen at the bottom of the distributary channel sand body, mainly grayish green conglomerate and glutenite upward, and gravel mudstone and sandy mudstone formed by the distributary Bay are developed at the upper part.

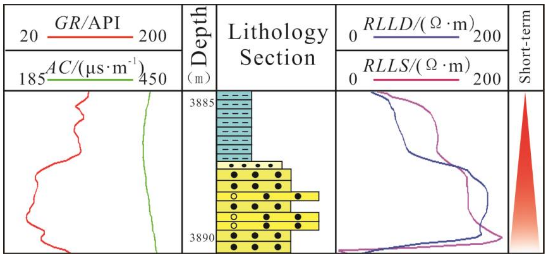

Figure 3. Upward "deepening" asymmetric short-term cycle,High accommodation(Ma18,$T_1b_2^3$)

(2)Upward "shallowing" asymmetric cycle

This type of study area is mainly developed in the estuarine bar sedimentary area at the end of T_1b_3 and T_1b_2 members. Its sedimentary characteristics are that it can only completely preserve the sedimentary records of the falling half cycle, and the rising half cycle is not developed or is dominated by the water inflow scouring surface.

This type can be further divided into two subtypes: low accommodation type and high accommodation type

The low accommodation space type develops an accretionary and weakly progradational stratigraphic sequence composed of the front Delta and far sand bar formed by a brief regression under the background of the overall lake transgression. The top is mainly the scouring surface of lithological gradual change mutation or the scouring surface of channel sand body undercutting overlap and lithological mutation, and the bottom is black mudstone and gravel mudstone that changes upward into grayish green sandstone and glutenite. This type is mainly developed in the subfacies of the outer front of the fan delta at the end of the T_1b_2 member(Figure 4).

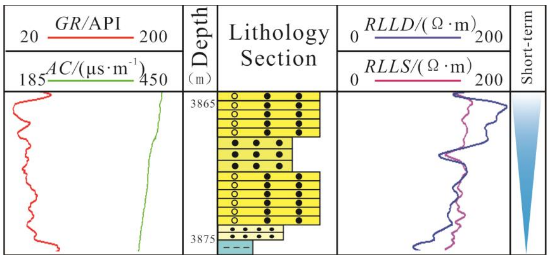

Figure 4. Upward "shallowing" asymmetric short-term cycle,Low accommodation(MaD5824,$T_1b_2^2$)

The upward "shallowing" asymmetric cycle of high accommodation space type, under the background of the increase of accommodation space, often shows an upward thickening and shallowing aggradation weak progradation sequence composed of fine sandstone, siltstone, fine conglomerate and silty mudstone. This subtype is developed in the outer front of fan delta and pre delta subfacies of T_1b_3 member(Figure 5).

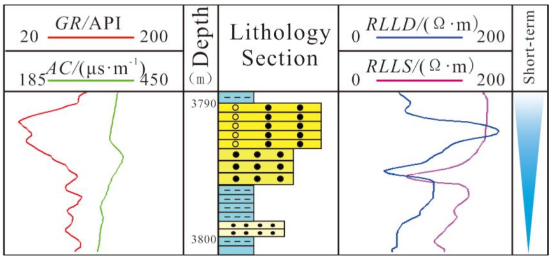

Figure 5. Upward "shallowing" asymmetric short-term cycle,High accommodation(MaD5124,$T_1b_3{}^1$)

(3)Symmetrical cycle

This type of study area is mainly developed in the T_1b_3 section, which is mainly found in the estuary and both sides of the alternating action of underwater distributary channel and estuary dam. During the formation of this type of structure, both the rising and falling half cycles of the base level cycle have sedimentary records. The cycle is bounded by the Lake flood surface and the flood surface, and is composed of the superposition of the reverse rhythm that coarsens from the top down and the positive rhythm that thins from the bottom up. It has a complete time unit boundary, and a relatively complete progradation retrogradation progradation symmetrical sedimentary sequence is developed in the sequence(Figure 6).

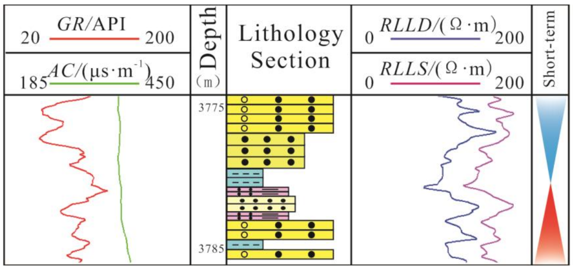

Figure 6. Symmetrical short-term cycle(MaD5824,$T_1b_3{}^1$)

4.2 Selection of high resolution sequence correlation interface

The identification of sequence boundary is the basis of sequence division and the establishment of isochronous sequence framework. Summarizing the identification marks of sequence boundary is of great significance for the correct division of sequence stratigraphy.

4.2.1 Characteristics of top boundary of Baikouquan formation

Baikouquan formation is a long-term base level cycle, and the top interface is the largest lake flooding surface of Baikouquan formation in the study area. It is the transition interface between a set of fine debris deposits in the late deposition of Baikouquan formation and a set of gray and grayish green sandstone (gravel) deposits in Kexia formation. It is characterized by the sudden change of low resistivity mudstone section to high resistivity glutenite section in logging.

4.2.2 Characteristics of bottom interface of Baikouquan formation

Baikouquan formation as a whole is a shallow water fan delta deposit formed during the period of long-term base level rise. The bottom of Baiyi formation is characterized by the deposition of thick sandy conglomerate superimposed by multi-stage distributary channels under the low accommodation space, which is in unconformable contact with the underlying Permian strata. An obvious sequence boundary (P_2w) can be identified on the Triassic seismic profile. The seismic profile is characterized by strong amplitude continuous reflection, which can be traced and compared in the whole study area. The logging curve shows sudden changes in lithology and electrical property. The Wuerhe formation below the sequence boundary is gray mudstone and medium fine sandstone, with low resistance and serrated resistivity. The Baiyi formation above the boundary is gray massive sandy conglomerate, with high resistance as a whole.Low GR characteristics(Figure 7A).

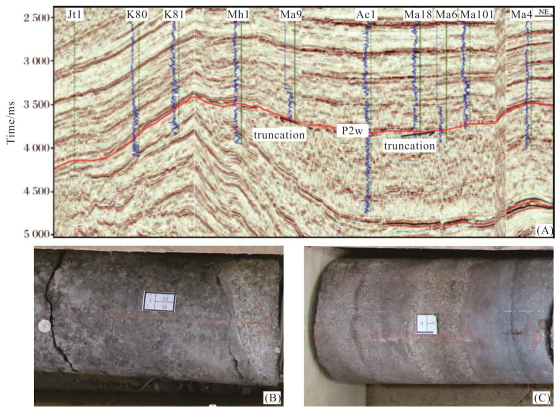

Figure 7.(A)Seismic profile response characteristics of sequence boundary at the bottom of Baikouquan formation in Mahu sag(according to [28],revised); (B)Core photos of scouring surface at the bottom of river channel(Ma18); (C)Core photos of Lake flooding surface at the top of Baikouquan formation(Ma601)

4.2.3 Characteristics of medium and short term base level cycle interface in Baikouquan formation

(1)Scouring surface at the bottom of distributary channel

Erosion erosion erosion surface or unconformity surface of the same origin and scale is an important reference mark for dividing different levels. According to core observation of coring wells, a small scouring surface is developed at the lower part of T_1b_3, and the sedimentary characteristics above and below the interface are obviously different, which is shown as the contact mutation between the mudstone at the bottom and the coarse sandstone at the upper part, and the mudstone at the bottom and the conglomerate at the upper part. It is located at the bottom of the base level cycle, reflecting the sedimentary background of the base level falling to the lowest point, low accommodation space and low a/s ratio.

The river channel is relatively developed and the river power is strong. It can be used as one of the identification marks of medium and short-term base level cycles in the study area(Figure 7B).

(2)Flood surface and Lake flood surface at all levels

It represents the period when the datum level rises to the maximum position in different levels of datum level cycles and can accommodate the largest space, and it is an important reference plane for identifying all levels of datum level cycles. The maximum flooding surface is the mark of the top boundary of the transgressive system tract. With the rapid rise of lake level, the accommodation space increases rapidly in the vertical direction, and the sediment supply rate is less than the accommodation space growth rate. The horizontal shoreline of the lake is constantly migrating to the land direction. The basin is in an under compensated state, lacking a large number of clastic deposits, mainly mechanical suspension deposition and chemical deposition. Lithology is usually fine-grained argillaceous sediment, and horizontal bedding is often developed; The overlying strata of the maximum flooding surface often show upward thinning progradational and retrograde sequences, while the overlying strata are mostly progradational sequences. The maximum flooding surface is located at the inflection point of the upward thinning logging response and the upward coarsening logging response(Figure 7C).

(3)Regional, local isochronous reference plane

The regional standard isochron has the characteristics of wide distribution, obvious characteristics and easy to determine. Through its accurate comparison, it can control the correlation of long-term base level cycle sequences, master the changes of long-term base level cycle sequence thickness level, and then guide the comparison of internal base level cycle sequences at all levels. Regional marker layer 1: At the top of $T_1b_3^{1}$, the GR value suddenly changes from high to low, and the resistivity is high. During this period, the lake transgression was strengthened. Vertically, it was mainly lacustrine mudstone. The thin sandstone on the top of $T_1b_3^{1}$ can be well tracked in the whole area. This marker layer can well control the correlation of the upper Baikouquan formation. Regional marker layer 2: in the middle of $T_1b_3^{2}$, during the process of water entry, there was a brief water retreat, forming a set of light gray and gray glutenite with large area, and the characteristics of low gamma and high resistance are obvious. This sedimentary transition interface is an ideal contrast marker. It also plays a guiding role in the identification of ultra short-term base level cycle sequences in the late T_1b_3 member. Regional marker layer 3: a set of thick gray glutenite deposits are developed at the upper part of the scouring surface at the bottom of $T_1b_3^{3\text{-}2}$, and a set of grayish brown, dark gray mudstone and argillaceous sandstone are located at the lower part. This sedimentary transition surface is the mark for the division of T_1b_3 and T_1b_2 members. Regional marker layer 4: The upper part of $T_1b_1^{3\text{-}2}$ bottom lithology conversion surface is a set of sandy conglomerate with low GR, low SP and high resistivity. The bottom curve returns obviously, and mudstone with high GR and low resistivity appears. This marker bed is very important for stratigraphic correlation at the bottom of Baikouquan formation.

There are thin rock layers with special electrical characteristics caused by different levels of flooding in Baikouquan formation. Its bottom interface plays a controlling role in the comparison of local short-term cycle base level interfaces (local standard layers A, B, C). This interface becomes a local isochronous reference plane. Although these markers are not widely developed, they can realize the identification and comparison of medium-term and short-term base level cycle interfaces in Baikouquan formation in the whole region through the alternative connection comparison.

5. Discussion

5.1 Stratigraphic development characteristics of Baikouquan formation

Fine correlation results of short-term base level cycle sequences show that there is little difference in stratigraphic thickness between short-term cycles horizontally in the study area. Generally, the area and interval where mudstone is developed are relatively small in thickness; The formation thickness is relatively large in the area and interval where sandstone is developed; Vertically in the study area, the short-term base level cycles of the T_1b_1 and T_1b_2 are asymmetric as a whole. Because the Baikouquan formation was in the background of water regression during the deposition period, the asymmetric short-term base level cycles are developed in the ascending half cycle than the descending half cycle, and the thickness is significantly larger than the descending half cycle; Due to the development of delta front, the symmetrical short-term base level cycle at the top of Baisan member has an asymmetric structure of descending half cycle significantly larger than ascending half cycle(Figure 8).

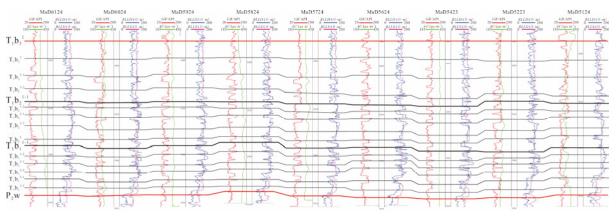

Figure 8. East West high-resolution sequence stratigraphic correlation profile of Baikouquan formation (vertical source direction).

5.2 Control of base level cycle change on phase sequence and phase domain

According to the sedimentary facies development process of Baikouquan formation in the western slope of Mahu Sag, the characteristics of facies sequence and facies association are closely related to the changes of base level cycles. In the regressive shallow water fan delta depositional system in this area, the process of base level change is closely related to the process of lake level rise and fall, and the rise of base level corresponds to the rise of lake level, and vice versa. The Baikouquan formation is generally an upward deepening asymmetric cycle of long-term base level rise, including the early stage of slow base level rise, the middle stage of continuous base level rise, and the late stage of rise to the near symmetric cycle of the Baikouquan formation. With the change of base level, the sedimentary facies of the whole Baikouquan formation also changed accordingly. The base level at the bottom of the Baikouquan formation fell or approached the lowest point, with the characteristics of low accommodation space and high sediment supply rate, thus forming a large-scale rapid lake basin facies shift, the flood plain and distributary plain rapidly expanded, and the fluvial effect enhanced, thus forming a highly developed high-energy River controlled shallow water fan delta depositional system. With the rise of the base level, it began to move towards the continental facies, and the flood plain and distributary plain decreased until they disappeared, entering the fan delta front facies domain. Finally, with the rise of the base level to the highest point, the sedimentary facies gradually evolved into the front fan delta facies domain. It can be concluded that the Baikouquan formation as a whole is a set of retrograde stratigraphic style, its bottom is the water retrograde pole, and the base level is in the rising process as a whole. In terms of sedimentary facies, it gradually transits from the inner front of fan delta to the front fan delta, and vertically (from bottom to top) from underwater distributary channel → front sheet sand → front fan delta mud (T_1b_3).

5.3 Control of base level cycle on reservoir

The superposition of different levels of base level cycles controls the distribution of sedimentary facies, and then controls the distribution of reservoirs. The medium-term base level cycle has the strongest control effect on reservoirs. During the depositional period of Baikouquan formation, the early stage of T_1b_1 and T_1b_2 members mainly developed asymmetric medium-term cycles that deepened upward. The early stage of base level cycle rising half cycle had small accommodation space, abundant material supply, distributary channel sand bodies were developed, sand bodies were overlapped inside, sand bodies had good connectivity, and oil-bearing reservoirs were widely distributed. It was the main reservoir system in the west slope of Mahu sag. The late T_1b_2 and early T_1b_3 members mainly developed the late half cycle of asymmetrical medium-term cycle base level rise, which deepened upward. The single sand body had a thinning and thinning trend, indicating that with the increase of accommodation space, the supply of material sources decreased, and vertically it was sand mud interbedding. The plane sand channel sand bodies were mostly independent of each other, and the connectivity became poor, and the reservoir performance became poor. However, the mud distribution area between distributary channels was wide, which could become a good local cap rock and barrier layer, creating favorable conditions for lithologic reservoir accumulation. During the deposition period of T_1b_3, the lake water transformation increased significantly, the thickness of the sand body decreased, the grain size of the sand body became finer, and the physical properties became worse. During this period, a large area of front fan delta mud developed, forming a good regional cap rock. Several nearly East-West compressional and torsional faults formed during the Hercynian Indosinian period communicated (quoted) the Baikouquan formation with the source rocks of the lower Permian Urho formation, provided oil and gas migration channels, and formed lithologic structural oil and gas traps in the west slope of Mahu sag.

6. Conclusions

1.According to the drilling, logging, core and seismic data of block Ma 18 in Mahu sag, the Baikouquan formation developed an asymmetric cycle of long-term base level rise (LSC), which included three middle-term cycles, corresponding to the early nappe shallow water fan delta inner front deposition (MSC_1), the middle fan delta outer front deposition (MSC_2) and the late front fan delta deposition (MSC_3) of the Baikouquan formation.

2.Through further identification of sequence boundaries, there are three types of short-term cycles (upward "deepening" asymmetric short-term cycles, upward "shallowing" asymmetric short-term cycles, and symmetrical short-term cycles) in the study area, which are subdivided into five subcategories according to the change of accommodation space.

3.Based on the long-term, medium-term and short-term cycle base level sequence boundary identification marks of Baikouquan formation, a high-resolution sequence stratigraphic framework was established in the study area. Through the inter well control of standard layers and marker layers at all levels, the correlation of base level cycle sequences at all levels of Baikouquan formation in the study area was completed.

4.The favorable area for reservoir development in Baikouquan formation is the early thick glutenite channel microfacies sedimentary area of MSC_1 and MSC_2. These sand bodies are vertically overlapped with each other, with good internal connectivity and large distribution of oil-bearing reservoirs, which are the key horizons for oil and gas exploration and development.

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