Journal of Geoscience and Environment Protection, 2022, 10, 156-169
https://www.scirp.org/journal/gep
ISSN Online: 2327-4344
ISSN Print: 2327-4336

Division and Correlation of Lacustrine Gravity Flow Reservoirs Based on High-Resolution Sequence Stratigraphic Analysis—Taking Oil Formation I of Lower Es3 in Wuhaozhuang Oilfield as an Example

Yiming Zhang[1,2*], Hongliang Wang[1,2,3]

[1]School of Energy Resources, China University of Geosciences, Beijing, China
[2]Key Laboratory for Marine Reservoir Evolution and Hydrocarbon Abundance Mechanism (Ministry of Education), China University of Geosciences, Beijing, China
[3]Key Laboratory for Shale Gas Exploration and Assessment (Ministry of Land Resources), China University of Geosciences, Beijing, China
Email: *zym981210@126.com

How to cite this paper: Zhang, Y. M., & Wang, H. L. (2022). Division and Correlation of Lacustrine Gravity Flow Reservoirs Based on High-Resolution Sequence Stratigraphic Analysis—Taking Oil Formation I of Lower Es3 in Wuhaozhuang Oilfield as an Example. *Journal of Geoscience and Environment Protection, 10,* 156-169.
https://doi.org/10.4236/gep.2022.106010

Received: May 27, 2022
Accepted: June 27, 2022
Published: June 30, 2022

Abstract

The phase change of lacustrine gravity flow deposition is fast and complex. In its reservoir division and correlation, the isochronous problem is very important. Taking the oil formation I of Es3 in Wuhaozhuang oilfield as an example, through the analysis of stratigraphic drilling and logging data in the study area, according to the genetic types of different levels of base level cycle interfaces and the characteristics of high-resolution sequence stratigraphy, this paper subdivides the lacustrine gravity flow oil layer of lower Es3 in Wuhaozhuang Oilfield, divides it into four short-term base level cycle sequences, and establishes the high-resolution isochronous stratigraphic framework of this interval. It is found that the mid-term, short-term and ultra short-term base level cycles correspond to the oil formation, sand layer group and single layer in the oil layer correlation unit of the oilfield respectively. Based on this, the oil layer correlation unit of the interval is divided, and the sublayer correlation model is established according to the identification characteristics of the short-term base level cycle.

Keywords

High-Resolution Sequence Stratigraphy, Formation I of Lower Es3, Reservoir Division and Correlation, Lacustrine Gravity Flow, Wuhaozhuang Oilfield

1. Introduction

High-resolution sequence stratigraphy is based on three-dimensional outcrop, drilling, logging and high-resolution seismic data, through the identified multi-level base level cycle strata, to carry out high-precision time-resolution genetic sequence division and sublayer correlation (Yan et al., 2016). In the mid-1990s, Cross (1994) put forward this theory for the first time, and took the datum as the division mark of time stratigraphic units under the high-precision isochronous stratigraphic framework. The change of datum describes the relative relationship between the accommodation space change and the sediment supply in the deposition process. Then Deng (1995) introduced it into China to study and summarize the application methods of high-resolution sequence stratigraphy in different continental sedimentary systems. Xu (1997) further improved the adaptability of high-resolution sequence stratigraphy in the study of continental sedimentary strata, but lacked consideration of auto-cycle events. Since then, Chinese scholars have made a lot of achievements in practical application on the basis of previous theoretical research (e.g. Zheng et al., 1999; Deng et al., 2000; Wang & Liu, 2004; Zheng et al., 2001). Among them, Zheng et al. (2001) proposed six types and significance of base level cycle division of continental basins after refining the characteristics of high-resolution sequence stratigraphy in many regions. In recent years, the theory of high-resolution sequence stratigraphy has been improved day by day. Now it has been combined with the fields of mathematical geology and computer, and the application of this theory and technology has been realized in many fields except oil and gas development (Ye, 2018; Liang et al., 2022). However, at present, the division standard of base level cycle level has not reached a unified level. After systematic research, experts and scholars generally believe that the theory of high-resolution sequence stratigraphy has extremely important value in the exploration and development of continental sedimentary strata (Xu, 1997; Wang & Liu, 2004; Zhang et al., 2008; Hu, 2019). It can be used to discover and predict high-quality reservoirs in the field of reservoir geology and carry out refined reservoir description, so as to lay a foundation for the geological research of oil reservoirs in the middle and later stage of development.

Es3 member in Wuhaozhuang oilfield area of Gubei sub-sag was strongly subsidence during the evolution of fault basin, and gravity flow deposition was widely developed in the center of Lake Basin (Shi, 2016). The sedimentary reservoir of this horizon advances layer by layer underwater to the depth of the lake basin, forming multi-stage fan deposition. The complex superposition relationship between turbidite sand bodies in the lake basin makes the internal development characteristics and distribution law of the stratum unclear. In recent years, some scholars have carried out theoretical research on high-resolution sequence stratigraphy of lacustrine gravity flow in Wuhaozhuang area, but the research accuracy is not high, and the internal auto-cycle sedimentation events of lacustrine gravity flow are not fully considered in comparison (Lou, 2019; Ma et al., 2016). Therefore, taking the oil formation I of the lower member of Es3 in Wuhaozhuang oilfield of Gubei sub-sag as an example, according to the division principle that the mid-term, short-term and ultra short-term base level cycles correspond to oil formation, sand group and sublayer respectively, this paper divides multi-level base level cycles in the study area, establishes a reasonable and fine isochronous stratigraphic correlation framework, divides the oil formation I into four sand groups, and divides the correlation sublayer under the control of base level cycle.

2. Geologic Setting

Gubei sub-sag is located in the northeast of Zhanhua sag in Jiyang depression. It is a double fault lake basin developed on Mesozoic sag in Cenozoic (Qiu et al., 2019). Gubei sub-sag is close to the Tanlu fault zone, with an area of about 500 km^2 and geological reserves of about 5.47×10^7 tons, which is connected with the peripheral buried hill (uplift) through the peripheral fault (**Figure 1**). The interior includes three sub-sag, i.e. Zhuangxi sub-sag, Gubei East sub-sag and Gubei West sub-sag, as well as two north-south positive structural units, i.e. Zhuangnan and Gubei nose structural belts. It has a structural pattern of "North breaking and South exceeding", i.e. opening from northeast to southwest (Xin, 2014). Block 52 of Wuhaozhuang oilfield is located in the central syncline of the East sub-sag of Gubei sub-sag. It is a medium high permeability structural lithologic reservoir formed with the Zhuang 52 fault and the reverse tectonic movement of "rising in the north and falling in the South" (Pu et al., 1998). It is now in the stage of water control, oil stabilization and comprehensive treatment (Duan et al., 2020). The Paleogene Shahejie formation is the main development layer system in this area, which is divided into four layers: Es1 to Es4. The total

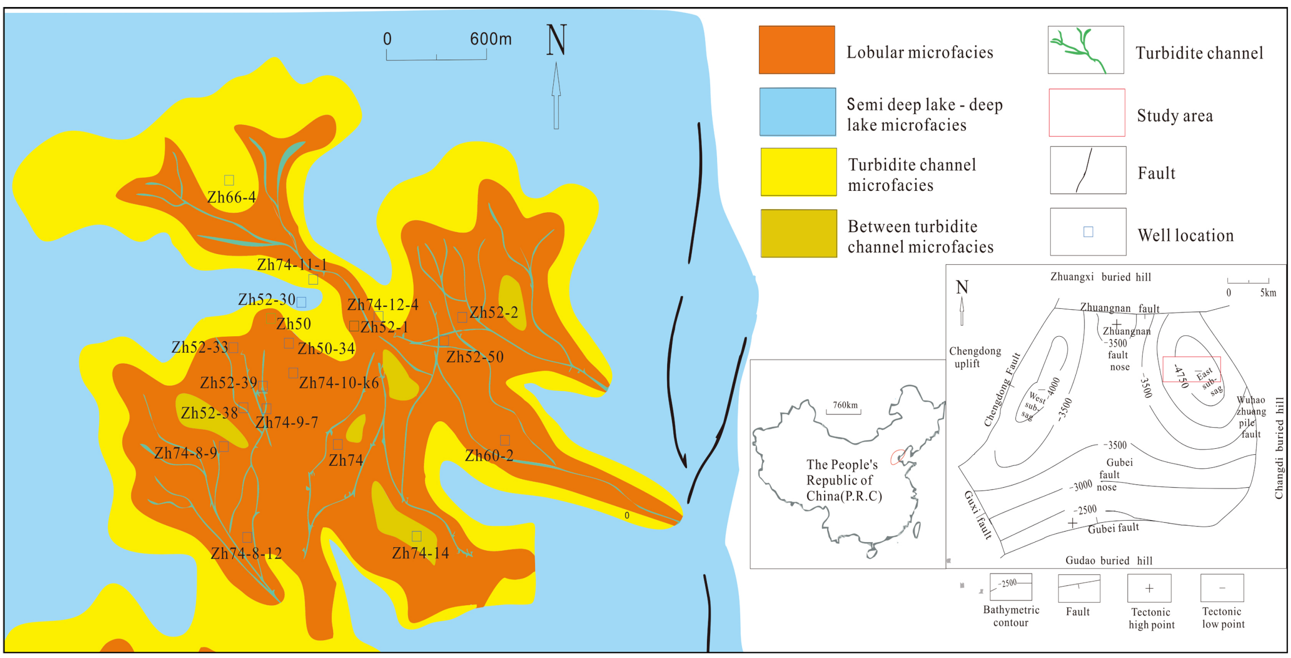


Figure 1. Location and sedimentary background map of the study area of Es3.

thickness of the stratum is about 1120 m, and the lithology is mainly mudstone, oil shale, pebbly sandstone, etc.

3. High-Resolution Sequence Stratigraphic Analysis of Lacustrine Gravity Flow

During the whole sedimentary period of Es3 member in Gubei sub-sag, the basin basement continued to subside and the lake area continued to expand. The paleocurrent carried the debris of Gubei uplift on the south side of Wuhaozhuang oilfield (Pu et al., 1998), and flowed from the cliff to the fault depression lake basin along the fault step belt of Gubei fault, resulting in multi-stage lacustrine fan deposition in the study area. The sediments in the basin are generally coarse-grained, thick sand bodies with strong reservoir heterogeneity, which is very difficult in oil and gas exploration.

3.1. Correspondence between High-Resolution Sequence Stratigraphic Units and Oil Layer Correlation Units

Oil layer correlation is the subdivision and correlation of known oil-bearing strata according to the connectivity of permeable layers and the distribution of non-permeable layers within the scope of the oil field based on the isochronous correlation of regional strata. Combined with the characteristics of petroelectric and sedimentary cycles, and according to the consistency and vertical connectivity of oil layer characteristics, the simple oil-bearing strata can be divided into four oil-bearing units from large to small, including oil-bearing series, oil formation, sand group and single oil layer. If the situation of oil-bearing strata is complex, it can be divided into five levels of oil layer correlation units from large to small, namely oil-bearing series, oil formation, sand group, sublayer and single layer. The smaller the level of oil layer correlation unit, the better its vertical connectivity and physical properties. The medium and short-term cycles of sequence stratigraphy are divided into 6 periods of base level, medium and short-term cycles and super-high cycles (Zheng et al., 2001; Wang & Liu, 2004). Following the principle of reservoir development, Chen et al. (2007) put forward the oil layer division and correlation scheme bounded by argillaceous caprock or septum and interlayer deposited on different levels of Lake flooding surface. Based on this, the long-term, mid-term, short-term and ultra short-term base level cycles of sequence stratigraphic correlation unit correspond to oil-bearing series, oil formation, sand group and single oil layer (sublayer) of oil layer division unit respectively, and its interface is Lake flooding surface of corresponding levels. The division scheme has important guiding significance for the correct division and correlation of sand group, sublayer sand body and single sand body in the stage of oil and gas development.

In the lacustrine gravity flow sedimentary system, the long-term base level cycle is equivalent to one or several oil-bearing series in the oil-bearing correlation unit, including several oil formations with similar oil-bearing characteristics, forming the sedimentary stratigraphic framework. Its top and bottom are separated from adjacent layers by thick impermeable layers, so it is equivalent to source rock, reservoir or reservoir cap rock combination. For example, the lower member of Shahejie formation of Neogene in Wuhaozhuang oilfield is an oil-bearing series. The mid-term base level cycle corresponds to an oil formation in the oil layer correlation unit, which is composed of several sand groups with similar oil layer characteristics, and the top and bottom are covered with thick impermeable layers. Vertically, it is usually a complete sedimentary system type, such as sublacustrine fan sedimentary system. The short-term base level cycle corresponds to a sand group or sublayer (including multiple single layers) in the oil layer correlation unit, which is composed of several single (oil) layers with similar oil layer characteristics, such as the vertical superposition of multi-stage "channel and channel", "lobar body and lobar body" or "channel and lobar body" sand bodies in the sublacustrine fan sedimentary system, and the top and bottom are separated from the adjacent layers by relatively stable low permeability or non-permeability barriers. Vertically, it is usually one or two adjacent sedimentary subfacies, such as sublacustrine fan facies, inner fan subfacies, middle fan subfacies, outer fan subfacies or the combination of the two adjacent facies. The ultra short-term base level cycle corresponds to a single (oil) layer in the oil layer correlation unit, which is the smallest oil layer correlation unit. The top and bottom are separated from the adjacent layer by low permeability or non-permeability interlayer. Vertically, it is usually a sedimentary microfacies type, such as one-stage turbidite channel or lobar deposition, indicating a single-stage turbidite deposition event. Different levels of base level cycles represent corresponding levels of lacustrine transgressive and regressive sedimentary sequences. Due to the rapid deposition rate of lacustrine gravity flow, fine-grained sediments are easy to be eroded during deposition. Therefore, the horizontal continuity of single (oil) layer of oil-bearing strata is poor, the content of mud between sand bodies is small, and sand bodies pinch out and overlap occur frequently.

3.2. Identification of Base Level Cycle and Division of Oil Layer Correlation Unit

The base level is the lowest potential energy level of a surface (Cross, 1994). When the surface potential energy is high, it will be converted to kinetic energy and reduced to the lowest potential energy surface, that is, the surface equilibrium position (Li et al., 2019). The energy conversion is reflected in the deposition process, which is manifested in the erosion of the ground surface above the base level. Local and temporary sedimentation can be developed, but it cannot be preserved for a long time. Geological records of sediment formation will be stored on the surface below the base level through sedimentation. The base level will have wavy rise and fall relative to the surface, which is related to geological activities with different cycle time limits. In the process, it is accompanied by the fluctuation of accommodation space and sediment supply ratio (A/S), resulting in the change of vertical phase sequence, superposition style and geometric relationship of the stratum (Deng et al., 1996). Base level cycles of different levels can be identified accordingly. The oil layer correlation unit is identified by the corresponding relationship between sequence stratigraphy and oil layer correlation unit.

In the process of lacustrine gravity flow deposition, a complete mid-term base level cycle is composed of falling half cycle and rising half cycle, indicating that the fan complex is generated alternately by progradation and retrogradation, and recording the process of topographic gradient changing with time. When the base level drops to form a falling half cycle, the potential accommodation space shifts to the basin, and the A/S value decreases (A/S < 1). Horizontally, it reflects the process of fan progressive from the edge of the basin to the center of the basin. Vertically, it shows that the middle fan subfacies with higher gradient in the near source part of the fan are superimposed on the outer fan subfacies with lower gradient in the far source part of the fan. When the base level rises to form an ascending half cycle, the potential accommodation space in the landward direction increases as a whole, resulting in the increase of A/S value (A/S > 1). Horizontally, it reflects the process of fan body gradually retrograding from the center of the basin to the edge of the basin. Vertically, it shows that the outer fan subfacies with lower gradient in the far source part are superimposed on the middle fan subfacies with higher gradient in the near source part. The conversion position of the base level from rising to falling is the position of the maximum A/S value. In terms of drilling data, it corresponds to the maximum Lake flooding surface, showing relatively stable mudstone deposition, which has isochronal correlation significance. In addition, the mid-term base level cycle can also be divided according to the onlap surface and the progradation-retrogradation transition surface in the drilling data.

The conversion position of the base level from falling to rising is the position of the minimum A/S value, which is the time when the base level reaches the lowest point and the terrain gradient is the minimum before the land-oriented reconstruction of the terrain, indicating the position of the minimum topographic fluctuation of the sector in the lacustrine gravity flow sedimentary fan complex (Deng et al., 2001). It can be used as the dividing line of two time units of short-term base level cycle. In the drilling data, the specific manifestations are: the scouring surface at the bottom of the turbidite channel, the superelevation surface and the conversion surface of progradation to retrogradation (Wang, 2008). In terms of electrical data, the conversion surface can be identified by the change from funnel-shaped SP-GR combination with bottom gradual change and top sudden change to near bell shaped and box shaped SP-GR combination with bottom sudden change and top gradual change.

1) Scouring surface at the bottom of turbidite channel (**Figure 2(A)**): this surface is an unconformity surface formed when the late turbidite channel cuts

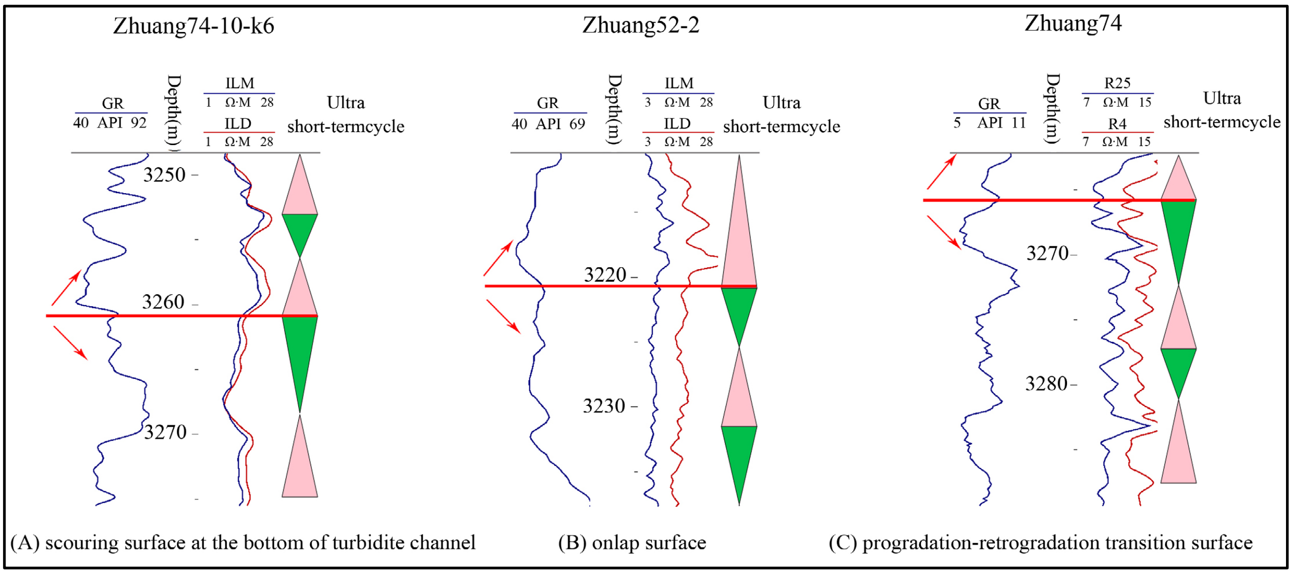


Figure 2. Base-level falling to rising transition surface.

the early lobar body deposition, which is mostly developed at the near source slope during the filling period of basin topography when the lake level drops. In the process of base level falling, when the minimum A/S value is reached at this level, the sand body at the bottom has experienced rapid scouring and undercutting of turbidite channel, the fine-grained material components are continuously taken away, and the physical properties of the sand body at the scouring surface are the best.

2) Onlap surface (**Figure 2(B)**): this surface is an unconformity surface formed by overlying strata in reverse (landward) upward sequence and overlying inclined strata. It represents the process of gradual rise after base level decline. It was formed in the period of basin topographic reconstruction when lake level rose rapidly. Later, due to the decrease of the velocity and density of gravity flow, the shale content continued to increase, and the retrogradation sequence of coarse in the lower part and fine in the upper part was developed.

3) Progradation-retrogradation transition surface (**Figure 2(C)**): this surface is the position where the stratum changes from progradation to retrogradation sequence. It is formed in the transition stage of base level falling first and then rising. It represents the process of topographic reconstruction after gravity flow sediments fill the low-lying areas of the basin.

3.3. Oil Layer Correlation and Sedimentary Development Evolution Controlled by Base Level Cycle

The accuracy of reservoir description is closely related to the scale of sublayer division. Developing high-precision sublayer division and correlation is the basic work to effectively observe the development and distribution characteristics of oil layers and analyze the sedimentary microfacies of reservoirs in the stage of oil and gas development. The high-resolution sequence stratigraphic correlation is carried out after the division of base level cycles at all levels and the establishment of high-resolution stratigraphic correlation framework. The stratigraphic distribution of isochronous stratigraphic units controlled by base level cycles has rules to follow, The example is the 3rd sand group form profile well Zhuang52-34 to Zhuang52-38 (**Figure 3(A)**): the base level falling half cycle is composed of progradational sequences formed at the low-lying areas filled when the A/S value of the basin is less than 1. At this time, the sedimentary sand body overlaps the sedimentary surface and advances to the lake basin, and the sediment grain size is coarse at the top and fine at the bottom (**Figure 3(B)**). The base level rising half cycle is composed of a retrograde sequence formed by topographic reconstruction when the basin A/S value is greater than 1. At this time, the sedimentary sand body overlaps to the land, and the sediment grain size is coarse at the top and fine at the bottom (**Figure 3(C)**).

Based on this, this paper selects well Zhuang52-50 with complete data and representative structural parts in Wuhaozhuang oilfield for oil layer correlation unit division, and organically combines Vail's sequence stratigraphy theory with Cross's base level cycle theory to carry out high-resolution sequence stratigraphy analysis of lacustrine gravity flow sedimentary system in the study area. According to the position of the transition surface of the base level cycle, a medium-term base level cycle sequence and four short-term base level cycles are identified in the oil formation I of the lower Es3, and four sand groups are divided accordingly (**Figure 4**).

According to the results of single well division, after the well by well oil layer comparison in the study area, the high-resolution isochronous stratigraphic framework of this layer is established. It is found that the buried depth of oil reservoir in oil formation I is 3180 - 3275 m, the whole middle part of the formation is thicker, the thickness decreases to the East and west sides, and two base level cycle types of symmetrical type and asymmetric type dominated by rising are developed. The average thickness of each sand group in the interval is 7.9 - 12.0 m, and the sand bodies are cut and overlapped with each other. The interlayer between sand bodies is relatively developed, with a thickness of 2.0 -

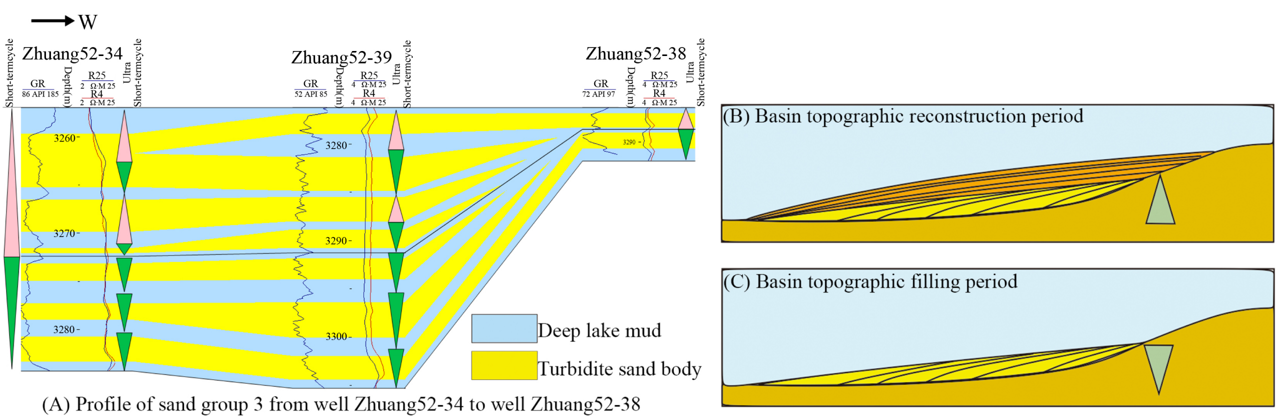


Figure 3. Examples and models of sublayer correlation in sequence framework.

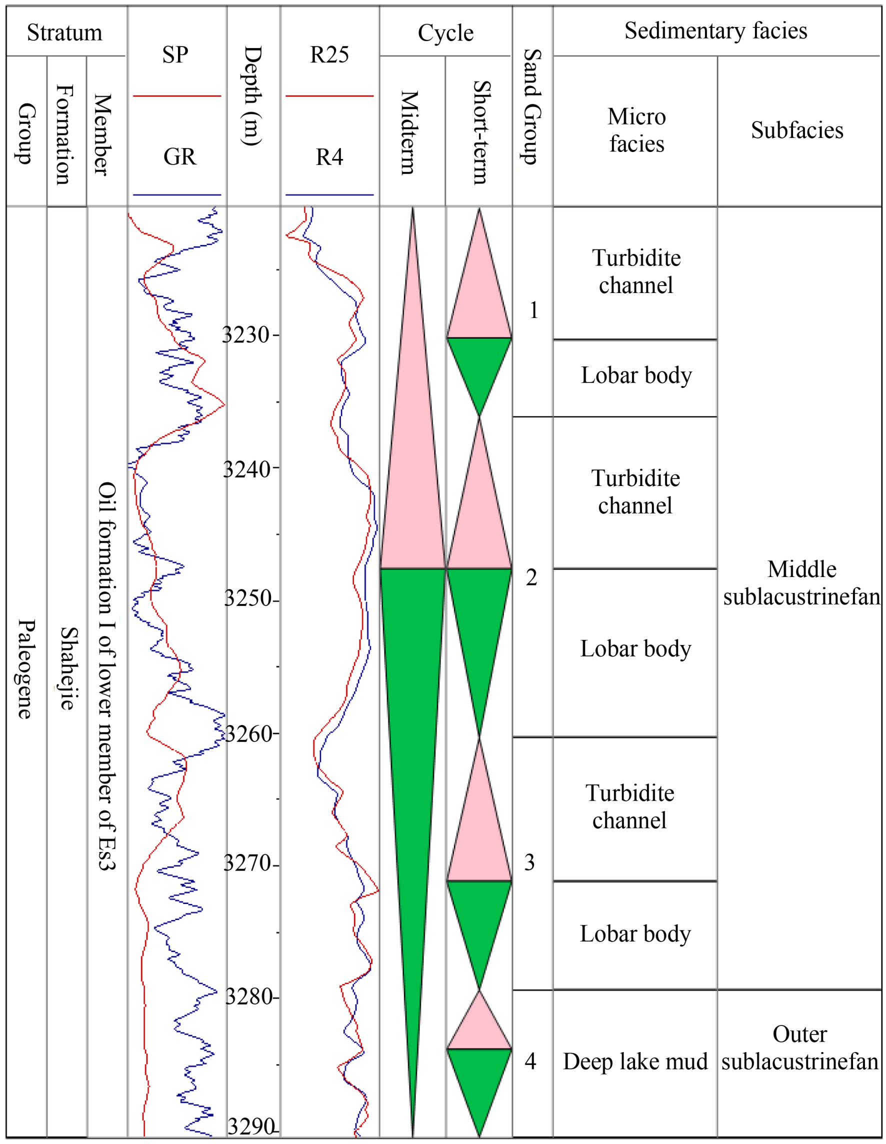
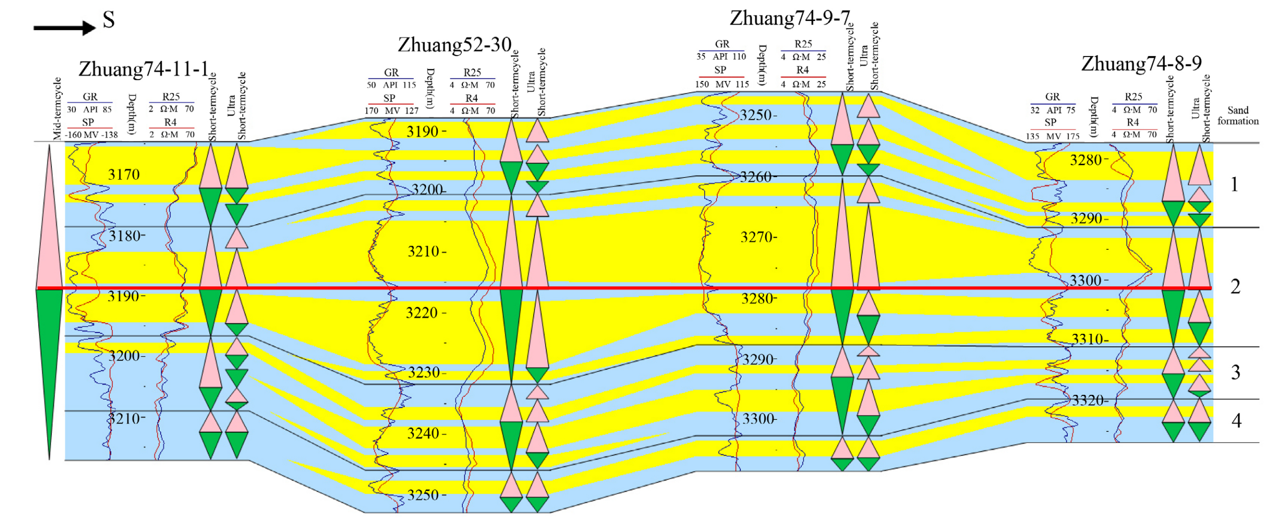


Figure 4. Sequence stratigraphic division of oil formation i of lower member of Es3 in well Zhuang52-50.

30.0 m. It is thin in the East and thick in the West as a whole.

The electrical characteristics are characterized by high natural gamma value, high acoustic time difference and low resistivity, which can be used as the top and bottom interface for sand layer division. According to the change of base level cycle and the migration law of accommodation space, the base level of the lacustrine gravity flow sedimentary system first decreased and then increased in the mid-term cycle, which represents the process of gradual transfer of accommodation space to the basin and then to the lake. It reflects the process of being controlled by the decline and rise of regional large-scale lake level with frequent fluctuations, the fan advancing into the basin, then retreating to the lake bank, and finally being gradually replaced by lacustrine fine-grained sedimentation, resulting in the fan filling for many times in the center of the lake basin and the development of filling turbidite complex caused by gravity flow and related sedimentary characteristics. Take the North-South along source direction profile and the East-West vertical source direction profile, i.e. from well Zhuang74-11-1 to Zhuang74-8-9 (Figure 5(A)) and from well Zhuang52-33 to Zhuang74-12-4 (Figure 5(B)).

According to the section along the provenance trend, A/S < 1 during the sedimentary period of sand group 3 and 4 and the early sedimentary period of sand group 2. At this time, the base level drops and the gravity flow sedimentary fan begins to develop. According to the principle of "sediment volume distribution", in the process of gravity flow entering the basin from the southern provenance area, it will produce vertical and lateral erosion undercutting at the structural slope or valley. With the continuous injection of sediments along the remaining grooves on the valley or ancient landform, a large number



(A) Correlation section of small layer from well Zhuang74-11-1 to Zhuang74-8-9 (Along source direction)

(B) Correlation section of small layer from well Zhuang52-33 to Zhuang74-12-4 (vertical source direction)

Figure 5. High-resolution sequence stratigraphic correlation section of oil formation i in lower member of Es3.

of progradational sequences are filled at Wells Zhuang52-30 in the low-lying area of the basin. At this stage, the water channel only plays the role of transportation. In the middle stage of 2 sand group sedimentation, the base level is at the transition position from falling to rising. At this time, the A/S value is the smallest. The low-lying areas of the basin are gradually filled and leveled by gravity flow sediments. After the topographic relief reaches the minimum position, the sedimentation is transferred, and the lower section of the bottom of the turbidite channel is developed or the road crossing scouring occurs. At the end of sedimentation of 2 sand group, A/S = 1. At this time, the base level begins to rise, the stratum is in aggradation type sequence, the thickness is uniform, and the sand body continuity is good. When 1 sand group was deposited, A/S > 1. At this time, the base level continued to rise, the sediments began to establish a new terrain, and the fan development entered the final stage. At this stage, the flow velocity of gravity flow slows down, the chip carrying capacity weakens, the undercutting and migration capacity of water channel decreases, unloading and accumulating at the center and edge of slope or valley, gradually filling with coarse clastic turbidite sandstone, and the terrain is continuously reconstructed landward. Specifically, the sand body gradually overlaps well Zhuang74-8-9, showing a retrograde sequence.

According to the vertical source direction profile, during the early deposition of sand group 3, 4 and 2, the base level decreased. When gravity flow enters the basin, it first fills the low-lying place, i.e. well Zhuang74-12-4, and then continues to deposit and fill with the stratum settlement at well Zhuang50. Deformation structures and bedding caused by gravity flow sedimentation such as loadcasts (**Figure 6(A)**), pillow structure and dish structure (**Figure 6(B)**). 2 sand group is in the transition position from base level falling to rising in the middle stage of sedimentation, the filling of low-lying parts of the lake basin is completed, and the basin topography is undulating and flat. In the late stage of sedimentation of 2 sand group, the base level rose and the basin topography recovered and reconstructed. With the gradual deposition and filling of turbidite channel, wave cross bedding (**Figure 6(C)**), or progressive bedding were developed on the scouring surface at the bottom of channel sandstone, the top gradually became sand mud interbedding, and structures and bedding caused by deep-water gravity flow sedimentation such as collapse deformation structure were developed (**Figure 6(D)**). During the deposition of sand group 1, the water body has reached a certain depth, and the end of the fan body is gradually covered by the low gradient outer fan subfacies with fine particle size, with parallel bedding and oblique bedding visible (**Figure 6(E)**).

In the actual comparison work, the "equal elevation slicing method" can be used to take the top and bottom surfaces of sand bodies equidistant from the same standard layer as the isochronous surface, and the sand bodies with similar lithology and thickness between the two isochronous surfaces can be divided into the same unit. However, for the superimposed sand bodies of "channel and

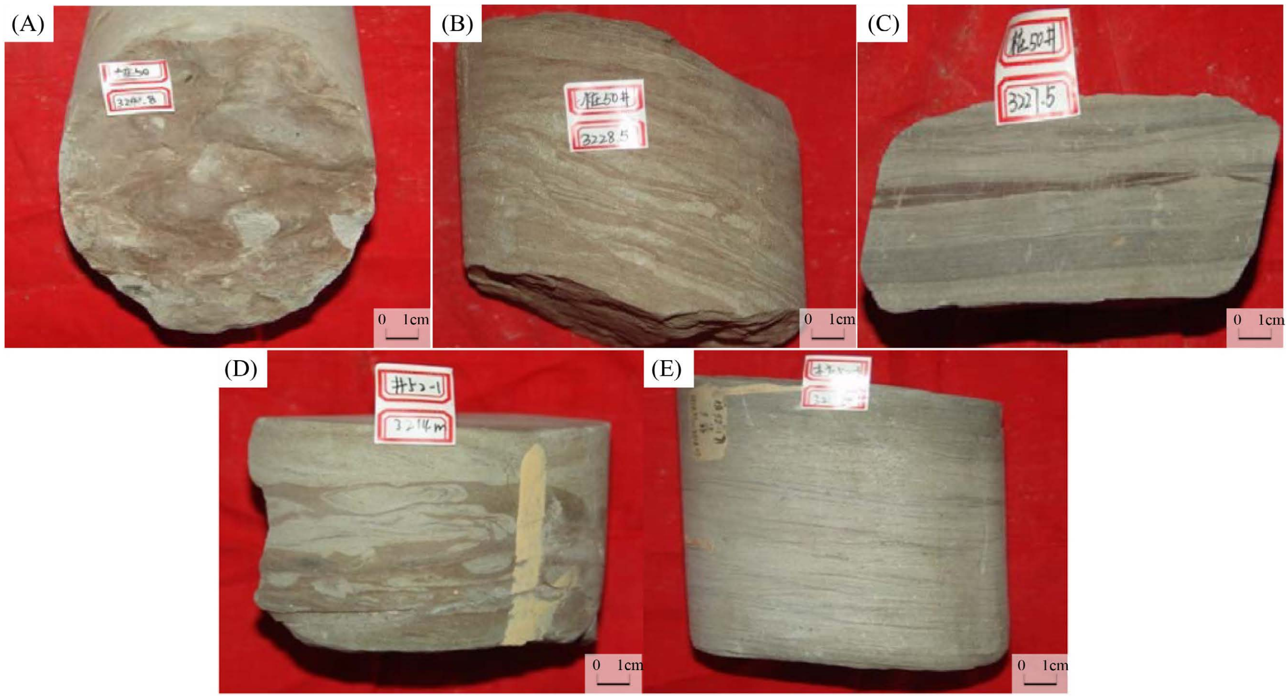


Figure 6. Core description of coring wells in the study area ((A) well Zhuang50 loadcasts at 3241.8 m, (B) well Zhuang50 deformation bedding at 3228.5 m, (C) well Zhuang50 Wave cross bedding at 3227.5 m, (D) well Zhuang52-1 Collapse deformation structure and wrapped bedding at 3218 m, (E) well Zhuang52-1 Parallel bedding and oblique bedding at 3213.5 m).

lobar body" formed under the scouring of turbidite watercourses under the background of lacustrine gravity flow sedimentary system, this method should not be used for "layer splitting". The time boundary of the interface should be taken as the bottom boundary of the unit. Therefore, the known stratigraphic data should be carefully applied in the actual comparison work, especially in the continental sedimentation, the factors such as Lake advance and lake retreat change frequently, resulting in the distribution of sedimentary sand bodies of various sedimentary microfacies in a certain small range and poor continuity. In the comparison results of the study area, it is reflected that the ultra short-term cycles of adjacent well locations cannot be corresponding section by section due to the influence of auto-cycle, Therefore, in the high-resolution sequence stratigraphy division and correlation of sedimentary bodies with event sedimentary properties, special attention should be paid to distinguish between auto-cycle and allo-cycle.

4. Conclusions

1) The oil-bearing series, oil formations, sand groups and sublayers of the oil-bearing correlation unit correspond to the long-term, medium-term, short-term and ultra short-term base level cycles of high-resolution sequence stratigraphy, and their interfaces are flood surfaces of corresponding levels. Based on this, one medium-term base level cycle and four short-term base level cycles are identified in oil formation I of lower Es3 in Wuhaozhuang oilfield, and four sand groups

are divided correspondingly.

2) The buried depth of reservoir in oil formation I is 3180 - 3275 m, and the average thickness of each sand group is 7.9 - 12.0 m. The interlayer between sand bodies is relatively developed, with a thickness of 2.0 - 30.0 m.

3) During the deposition of oil formation I, the formation phase transformation is complex and the continuity of sand body is poor. The ultra short-term cycles of adjacent well locations cannot be corresponding section by section due to the effect of auto-cycle.

4) For ultra short-term cycles, or even more precise cycle division and correlation, sublayer correlation should be carried out in combination with its sedimentary environment. This paper provides a method to establish a sublayer correlation model by using the filling and reconstruction law of basin topography during gravity flow sedimentation, that is, the base level falling half cycle is composed of progradational sequences formed when the basin topography fills the low-lying areas, and the base level rising half cycle is composed of retrograde sequences formed during the reconstruction of the basin topography.

5) In practice, the "channel and lobar body" superimposed sand body formed under the scouring action of turbidite channel should not use the equal elevation slicing method to "split the layer", and the scouring interface should be taken as the bottom boundary of the time unit.

Acknowledgements

The author thanks Prof. Wang Hongliang for being the corresponding author, and our works were funded by the National Science and Technology Major Projects Framework (Grant no. 2016ZX05033002-006).

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

Chen, J. S., Peng, J., Zhou, Y. et al. (2007). The Relation of Base-Level Cycle Sequence to Reservoir Division. *Journal of the Southwest Petroleum University, No. 2,* 162-165+196.

Cross, T. A. (1994). High-Resolution Stratigraphic Correlation from the Perspective of Base-Level Cycles and Sediment Accommodation. In *Proceedings of Northwestern European Sequence Stratigraphy Congress* (pp. 105-123). Holland: Elsevier.

Deng, H. W. (1995). A New School of Thought in Sequence Stratigraphic Studies in U.S. High-Resolution Sequence Stratigraphy. *Oil & Gas Geology, 16,* 89-97.

Deng, H. W., Wang, H. L., & Li, X. Z. (1996). Identification and Correlation Techniques of Sequence Stratigraphic Base-Levels and Their Application. *Oil & Gas Geology, 17,* 177-184.

Deng, H. W., Wang, H. L., & Ning, N. (2000). Sediment Volume Partition Principle: Theory Basis for High-Resolution Sequence Stratigraphy. *Earth Science Frontiers (China University of Geosciences, Beijing), 7,* 305-313.

Deng, H. W., Wang, H. L., Zhu, Y. J. et al. (2001). Identification Method of Gravity Flow

Sedimentary Base-Level and Its Application in Continental Basins. In *Abstracts of 2001 National Sedimentological Congress* (p. 25). China University of Geosciences.

Duan, C., Zhao, H., Sun, Z. et al. (2020). Application of Partial Pressure Water Injection and Energy Saving Technology in Zhuangxi Oil Production Plant. *Energy Conservation in Petroleum & Petrochemical Industry, 11,* 13-15+3.

Hu, R. Q. (2019). Research Status and Development Trend of High Resolution Sequence Stratigraphy. *West-China Exploration Engineering, No. 4,* 81-82+86.

Li, Y., Li, H., Wang, Z. H. et al. (2019). Effect of Base-Level Cycles on Sedimentary Sand Bodies in Continental Faulted Basins: Case Study of Beixi Area, Beier Depression, Hailar Basin. *Acta Sedimentologica Sinica, 37,* 858-867.

Liang, Y. L., Ge, J. W., Zhao, X. M. et al. (2022). High-Resolution Sequence Division and Geological Significance of Exploration of Marine-Continental Transitional Facies Shale in the 2nd Member of Shanxi Formation, Eastern Margin of Ordos Basin. *Natural Gas Geoscience, No. 3,* 408-417.

Lou, F. Q. (2019). Study on Reservoir Characteristics of the Shasanxia Sub-Member of Pile 23, No. 5 Oilfield. *Petrochemical Industry Technology, No. 6,* 212-213.

Ma, C., Yang, F. R., Yang, H. P. et al. (2016). Stratigraphic Correlation of Block Zhuang 52 in Wuhaozhuang Oilfield, Zhanhua Sag. *Technology and Industry across the Straits, 11,* 119-120.

Pu, R., Sun, W., Chen, Z. X. et al. (1998). Application of High Resolution Sequence Stratigraphy to Correlation of Progradational Oil Beds of Zh52 Turbidite Fan Reservoir. *Acta Sedimentologica Sinica, 16,* 21-26.

Qiu, L. W., Du, S. H., Dai, L. et al. (2019). Sedimentary Characteristics and Their Controlling Factors of the Third Member of Shahejie Formation in Gubei Sub-Sag. *Xinjiang Petroleum Geology, No. 2,* 161-167.

Shi, S. G. (2016). Turbidite Channel Sandbody Prediction and Lithologic Reservoir Exploration in Gubei Sub-Sag. *Special Oil and Gas Reservoirs, 23,* 16-20+151.

Wang, H. L. (2008). Concept of "Turnaround Surface" and Its Significance to Sequence Stratigraphy. *Earth Science Frontiers, 15,* 35-42.

Wang, S. M., & Liu, Z. J. (2004). Discussion on Some Problems of High Resolution Sequence Stratigraphy in the Study of Continental Stratigraphy. *Journal of Stratigraphy, No. 2,* 179-184.

Xin, Y. (2014). Hydrocarbon Accumulation in the Upper Submember of the 4th Member of the Shahejie Formation in the Gubei Sub-Sag, Zhanhua, Shandong. *Sedimentary Geology and Tethyan Geology, 34,* 72-77.

Xu, H. D. (1997). Some Problems in Study of Continental Sequence Stratigraphy. *Oil & Gas Geology, No. 2,* 3-9.

Yan, H. J., Jia, A. L., Guo, J. L. et al. (2016). Application of High-Resolution Sequence Stratigraphy to Fine Reservoir Description. *Xinjiang Petroleum Geology, No. 1,* 29-35.

Ye, X. M. (2018). Reservoir Description and 3D Characterization Study of S Oilfield. *Xinjiang Oil & Gas, No. 1,* 42-47+3.

Zhang, S. F., Zhang, C. M., Yin, Y. S. et al. (2008). High Resolution Sequence Stratigraphy in China. *Uranium Geology, 6,* 7.

Zheng, R. C., Peng, J., & Wu, Z. R. (2001). Grade Division of Base-Level Cycles of Terrigenous Basin and Its Implications. *Acta Sedimentologica Sinica, 2,* 249-255.

Zheng, X. W., Deng, H. W., Xu, H. D. et al. (1999). Automatic Recognizing Technique of Log High-Resolution Sequence Stratigraphy and Its Application. *Oil & Gas Geology, 20,* 357-360.