# Sedimentary Characteristics and Oil Control of Chang 7 Member in Zhidan Area, Ordos Basin

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**Abstract:** Deep-water gravity flow deposits are widely developed in the Chang 7 member of the Triassic Yanchang Formation in the Ordos Basin.Due to its complex formation mechanism and many types, it is a great challenge to predict its development scale and distribution law.Taking the Chang 7 Member in Zhidan area as an example, on the basis of fine core description, through sedimentary structure, grain size analysis and logging curve, the types and characteristics of sedimentary facies, logging facies and distribution of Chang 7 Member were studied.The results show that:(1)The Chang 7 member in Zhidan area develops delta front subfacies and semi-deep lake-deep lake subfacies, including underwater distributary channel, interdistributary bay, sliding-slump rock, sandy debris flow deposition, turbidite and semi-deep lake-deep lake mud.(2)The grain size probability accumulation curve of Chang 7 member develops one-stage, two-stage and three-stage. The one-stage mainly indicates turbidity current deposition, and the two-stage and three-stage mainly indicate underwater distributary channel deposition. (3)There are many types of sedimentary structures in the Chang 7 member. There are a large number of slump structures or heavy load molds in the sliding-slump rocks. The sandy debris flow deposits mainly develop massive bedding and mud-coated gravel structure. Turbidite common sand-mud frequent rhythmic interbedding, Bouma sequence and flame-like structure.(4)The delta front subfacies are distributed in the northeast, and the underwater distributary channel microfacies are developed. From Chang 73 to Chang 71, its distribution range gradually increases. The semi-deep lake-deep lake subfacies are distributed in the southwest, and the sandy debris flow is generally developed. From Chang 73 to Chang 71, its distribution range gradually decreases.This study can provide geological basis for the selection of sweet spot areas for shale oil exploration in the Chang 7 member of Zhidan area.

**Keywords:** Ordos Basin; zhidan area; Chang7 Section; sedimentary facies; gravity flow.

## 1. Introduction

With the deepening of geological research on unconventional tight oil and gas and shale oil and gas and the breakthrough of engineering technology, fine-grained sedimentary rocks adjacent to source rocks have become the main targets of oil and gas exploration[1]. Fine-grained sedimentary rocks are the main types of sedimentary rocks in terms of distribution scale and age. The oil and gas resources are very rich and have become an important field of oil and gas exploration. The fine-grained sedimentary rocks abroad are mostly distributed in the marine environment[2], while China has been dominated by the continental lake basin environment since the Mesozoic. Compared with the marine fine-grained sediments, the development scale of continental fine-grained sedimentary rocks is small, the reservoir heterogeneity is strong, and the research is difficult.

Fine-grained sediments are generally developed in the middle-lower Triassic Yanchang Formation in the Ordos Basin. Among them, the terrestrial fine-grained sediments developed in the Chang 7 member are mainly derived from the re-transport of river and delta sediments, and different types of gravity flow deposits are formed in the deep lake area[5]. The research on the sedimentary types of deep-water gravity flow in Yanchang Formation of Ordos Basin has gone through three stages : all the deep-water gravity flow deposits are attributed to turbidite sandstone, the sedimentary model of sublacustrine fan describes the sedimentary types of gravity flow, the sedimentary model of channel-sublacustrine fan and density current deposition. There are many trigger mechanisms for the formation of deep-water gravity flow deposits, which in turn affect the flow pattern, scale, type and distribution of sediments, which is the main reason why there is no unified understanding in academia so far. Therefore, the study of deep-water gravity flow deposits faces more challenges.

In recent years, the discovery of oil exploration in the Ordos Basin is mainly distributed in gravity flow sedimentary sand bodies and channel sedimentary sand bodies. A large number of oil fields have been discovered, including Huaqing, Heshui, Qingcheng, Xin 'anbian, Shanbei and so on. The annual increase in proven oil reserves exceeds $3\times10^8$ t, of which Chang 7 has accumulated proven oil reserves in Qingcheng Oilfield and Xin 'anbian Oilfield.$4.6\times10^8$ t, has become a new exploration layer for increasing oil reserves and production. The Chang 7 member of the Zhidan area in the central Ordos Basin has the geological conditions for large-scale accumulation of tight oil.However, after more than 10 years of exploration, only two blocks have submitted proven reserves, and the subsequent exploration areas are facing severe challenges. The distribution of sedimentary facies is one of the important factors controlling the distribution of tight oil. Previous studies in this area focused on the macroscopic and microscopic characteristics and evaluation of reservoirs, while the research on the types and distribution of sedimentary microfacies is still relatively weak. Therefore, based on the fine observation and description of the drilling cores of 12 exploration wells with a total of 237.74 m, according to the sedimentary structure and grain size characteristics of the cores, combined with the logging data of more than 700 wells, this paper comprehensively identifies the types of sedimentary facies of Chang 7, studies its sedimentary evolution characteristics, distribution law and its control on oil distribution, in order to provide geological basis for the next oil and gas exploration and dessert evaluation in this area.

## 2. Geological Background

The Ordos Basin is a multi-cycle and large continental depression basin developed on the basis of the Paleozoic cratonic basin. The basin is divided into six first-order tectonic units:Yimeng uplift, Jinxi flexural fold belt, Weibei uplift, Yishan slope, Tianhuan depression and western margin thrust belt. The basin spans five provinces of Shaanxi, Shanxi, Ningxia, Gansu and Inner Mongolia, and its main area is about $25\times10^4 km^2$. The basin has experienced the whole process of formation, development, depression and gradual disappearance. The sedimentary period of Chang 7 of Triassic Yanchang Formation is the heyday of lake basin development. The area is large and the deep lake area is widely developed, which creates special environmental conditions for gravity flow deposition[6]. According to the sedimentary cycle and the characteristics of the marker layer, the Yanchang Formation is divided into Chang 1-Chang 10 sections from top to bottom, a total of 10 oil layers.The Chang 7 oil layer group is further subdivided into three oil layer subgroups of Chang $7_3$, Chang $7_2$ and Chang $7_1$ from bottom to top. Among them, Chang $7_2$ and Chang $7_1$ mainly develop reservoirs, and Chang $7_3$ is mainly a hydrocarbon source layer. The Zhidan area is located in the central and southern part of the Ordos Basin and the center of the lake basin development of the Yanchang Formation, with an area of about $2440km^2$ . The shape of the bottom of the Chang 7 lake basin is gentle.At present, the whole structure shows a west-dipping monoclinic appearance, and at the same time, a west-dipping nose-like uplift structure is developed, and the structural amplitude is generally not more than 20m. The Chang 7 section of the study area has submitted a proven reserve of $625.85\times10^4$ t, and the proven oil-bearing area is $34.52km^2$. In addition to the proven reserves area, more than 40 industrial oil flow wells have been discovered in the Chang 7 section of the area. The daily oil production of single wells is 1.01~7.85 t, with an average of 2.47 t, showing a good exploration prospect.

## 3. Chang 7 Sedimentary Facies Types and Characteristics

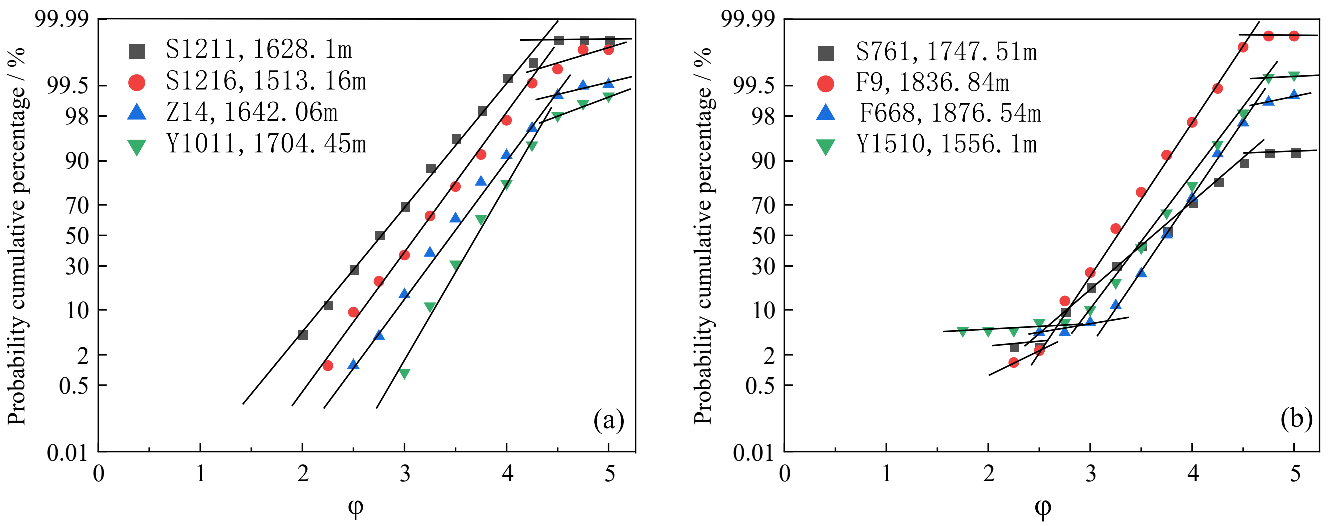
Based on the detailed observation and description of coring wells, combined with the grain size data, the sedimentary facies types of Chang 7 member in Zhidan area are divided into delta front subfacies and semi-deep lake-deep lake subfacies, which can be further subdivided into six sedimentary microfacies : underwater distributary channel, interdistributary bay, sliding-slump rock, sandy debris flow, turbidite and semi-deep lake-deep lake mud[7][8].

### 3.1. Delta facies

#### 3.1.1. Underwater distributary channel microfacies

The lithology of underwater distributary channel sand body is mainly gray and grayish brown fine sandstone. The sedimentary structure develops parallel bedding , plate cross bedding, ripple cross bedding and scour surface structure , indicating that it was formed in a high-energy and high-flow sedimentary environment dominated by traction flow[9]. In the sand bodies deposited at the bottom of the channel, a large number of elliptical sedimentary mud gravels are formed.

The grain size probability cumulative curve of Chang 7 in Zhidan area mainly develops two-stage and three-stage, among which the jump is the most developed, and the suspension and rolling are less. In the two-stage formula, the intersection point of the jump population and the suspension population is between 4 and 4.5, and the jump population particle size φ value spans from 2 to 4, indicating that the sediment particle size is medium to fine, the slope is basically the same, and the sorting is medium preference. In the three-stage type, the jump overall is still the most developed, and the rolling and suspension overall are less. The rolling overall grain size φ value is 1.75~2.5, indicating that the sediment grain size is coarse ; the overall particle size φ value of the jump is 2.5~4, the particle size is fine, and the sorting is from general to good.




a.Two-stage granularity probability accumulation diagram;
b.Three-stage grain size probability accumulation diagram.

**Figure 1.** Probability distribution diagram of sandstone grain size of underwater distributary channel in Zhidan area, Ordos Basin

### 3.1.2. Interdistributary bay microfacies

The lithology of the interdistributary bay is mainly gray silty mudstone, argillaceous siltstone and dark gray mudstone, mainly suspended deposition. Plant debris fossils are developed in the layer. Horizontal bedding and lenticular bedding are common in sedimentary structures, which are reflections of weak hydrodynamic conditions.

## 3.2. Lake facies

### 3.2.1. Sliding-slump rock microfacies

Due to the external unstable factors, the sand bodies accumulated rapidly in the delta front slide. During the sliding process, the mixed sediments of sandy and argillaceous sediments slide sharply along the slope to the deep lake area under the influence of gravity factors in the depression basin. The sand bodies are strongly deformed and curled, and the argillaceous sediments are more prone to deformation, which are wrapped and mixed with sandy sediments to form sliding-slump rocks[10]. The lithology of sliding-slumping sediments in Chang 7 member mainly includes gray-black silty mudstone and gray-brown siltstone. The sedimentary structures include gravel and sand ball, deformation structure, sandy injection body and enwrapped bedding, reflecting the complex and chaotic formation environment and strong hydrodynamic conditions of sliding-slump rock.

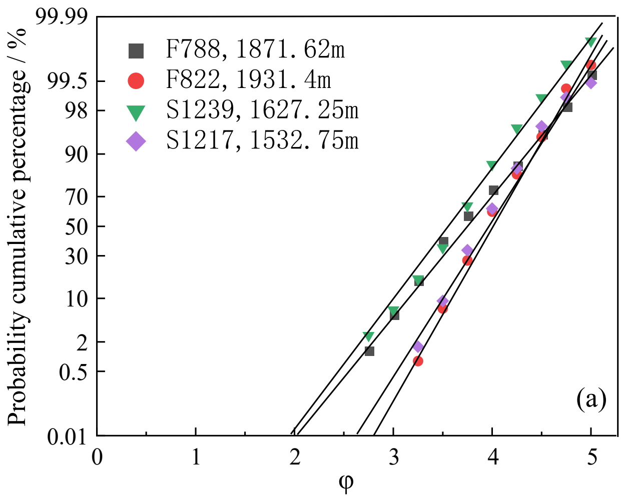
### 3.2.2. Sandy debris flow microfacies

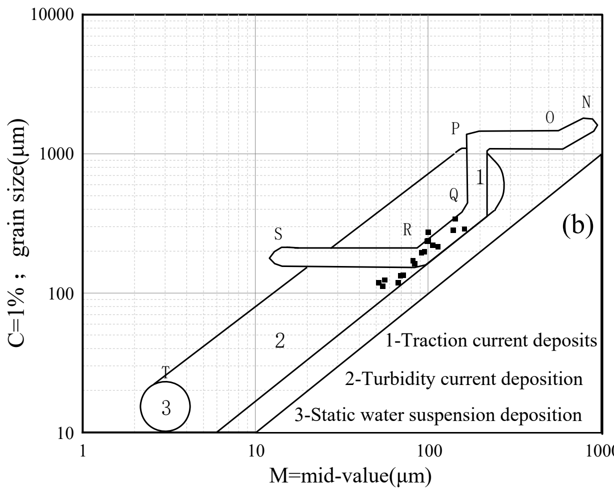
The concept of sandy debris flow was first proposed by Shanmugam[11].Sandy debris flow belongs to laminar flow, and sedimentary sand bodies may be transformed from sliding-slump rocks[12]. However, there are generally no signs of erosion in the interior and bottom of sandstone. The thickness of single sand body varies from 0.5 meters to several meters, which is a process of block transport. The sedimentary lithology of sandy debris flow in Chang 7 member is mainly light gray homogeneous massive fine sandstone or silt-fine sandstone. Mudstone tearing debris and massive bedding are common in sedimentary structures, which are important markers for identifying sandy debris flow deposits. Mudstone tearing debris is irregular in shape and non-directional, which may be formed by sliding-slump sandy sediments involved in muddy sediments and fluid transformation.

### 3.2.3. Turbidite microfacies

Sandy debris flow can be converted into turbidity current in the process of transporting to the center of the lake basin. Different from sandy debris flow, turbidity current belongs to turbulent flow, which is generally formed in an environment with relatively weak hydrodynamic conditions[13]. The lithology of Chang 7 turbidite is mainly gray siltstone-fine sandstone, argillaceous siltstone and siltstone and mudstone rhythmic interbed. The sedimentary structure shows that the sand body is in sudden contact with the semi-deep lake-deep lake mudstone, and the bottom of the sandstone sees the flame structure , and also the bottom model structure such as the heavy load model . The lithology becomes finer upward. The normal grain sequence bedding, horizontal bedding, the incomplete Bouma sequence, the common combination of A and E sections.

The grain size probability accumulation curve of Chang 7 turbidite is mainly one-stage ( Fig.2-a ), and the slope of the straight section is steep, indicating that the sediment sorting is good. The particle size φ value spans from 2.5 to 5, indicating that the sediment particle size is fine sand to silt. The formation mechanism is that the rapid decrease of water flow velocity leads to the rapid deposition of clastic materials, and the deposition is not stable enough, resulting in the frequent interbedded phenomenon of sand and mud. Most of the sample points in the C-M diagram are parallel to the C-M baseline ( Fig.2-b ), mainly distributed in the traction current deposition and turbidity current deposition areas. In the traction current deposition area, it is found that the sample points are mainly concentrated in the QR section, which represents the progressive suspension deposition, and the C value is proportional to the M value.




a.One-stage granularity probability accumulation diagram; b.C-M map of Zhidan area.

**Figure 2.** Grain size analysis of gravity flow deposits in Chang 7 member of Zhidan area, Ordos Basin

### 3.2.4. Semi-deep lake-deep lake mud microfacies

The water environment of the semi-deep lake-deep lake mud is mainly a reducing environment, and plant fossils are rare. The semi-deep lake-deep lake mud is formed by fine-grained sediment suspension deposition. The semi-deep lake-deep lake mudstone of Chang 7 member is mainly gray black mudstone or black shale, and the sedimentary structure sees massive structure and horizontal bedding. The massive mudstone flows in a suspended state under the action of gravity and forms in a quiet environment.

# 4. Logging Facies Characteristics

Logging facies is an important means to study sedimentary facies. Sedimentary facies analysis is mainly based on the amplitude, thickness, shape, smoothness and top-bottom contact relationship of logging curves. The types of logging curves of Chang 7 member in Zhidan area are various, mainly including box type, funnel type, low amplitude straight type, finger type and bell type, indicating different sedimentary microfacies types.

The types of underwater distributary channel microfacies logging curves in the study area are generally smooth box type, bell type or both composite type. The average GR value of the box-shaped curve is 75API, showing a low value, and the amplitude is higher and the width is larger. The upper and lower values of the section curve are almost the same, indicating that the sediment distribution is relatively uniform and the grain size is coarse. It reflects the strong hydrodynamic conditions and a continuous and stable vertical accretion process, and the source supply is sufficient. The lithology is mainly fine sandstone, and the sedimentary structure shows parallel bedding. The bell-shaped curve shows a low value, the upper part of the section shows a low amplitude, the lower part shows a medium-high amplitude and a large width, and the upper and lower values of the curve gradually increase from the bottom to the top, indicating that the sediment distribution is relatively uneven, the grain size is fine in the upper part and coarse in the lower part, showing a positive grain order. It represents the process of suspension unloading under strong hydrodynamic conditions, and reflects a process of lateral migration of rivers.

The type of interdistributary bay microfacies logging curve in the study area is generally low amplitude straight. The low-amplitude flat GR shows a low value, which has the characteristics of low amplitude and large width, representing the extremely insufficient source supply and a weak hydrodynamic condition. The lithology is mainly composed of silty mudstone, mudstone or shale, the grain size of the sediment is fine, and the sedimentary structure can be seen as horizontal bedding.

The types of sliding-slump rock microfacies logging curves in the study area are generally finger type and funnel type. The GR value of the finger curve is about 78API, showing a low value, with a low amplitude and a small width, representing a weak hydrodynamic condition. The curve value is high and low, the single layer thickness is small, the particle size is coarse and fine, and the grain order has no obvious regularity. The lithology is thin fine sandstone or argillaceous siltstone and thin silty mudstone or mudstone interbedded, indicating that the source supply is not sufficient and stable enough. The funnel-shaped curve shows a low value, the upper curve in the section shows a medium-high amplitude, the width is large, and the lower curve shows a low amplitude, which represents the process of increasing source supply and hydrodynamic conditions.The upper and lower values of the curve gradually decrease from the bottom to the top, indicating that the distribution of sediments is uneven. The grain size is coarse in the upper part and fine in the lower part, showing an inverse grain order. The upper lithology is mainly fine sandstone and argillaceous siltstone. The lower lithology is silty mudstone, silty mudstone and mudstone. The sedimentary structure shows slump deformation structure.

The type of sandy debris flow micro-phase logging curve in the study area is generally micro-toothed box type. The average GR value of the micro-teething box type is 101API, which is higher than the average GR value of the underwater distributary channel microfacies. It also shows that the sandy debris flow is located in the semi-deep lake-deep lake environment. The content of radioactive substances is high. The microdentation curve represents the process of sufficient but intermittent deposition of source supply, and the sediment heterogeneity is higher than that of underwater distributary channel microfacies. Typical sedimentary structures can be seen in massive structures.

The types of turbidite microfacies logging curves in the study area are generally bell-shaped and finger-shaped. The upper part of the curve is mainly composed of mudstone, silty mudstone and silty mudstone, and the lower part is mainly composed of argillaceous siltstone and fine sandstone, that is, the sediments are unloaded and deposited in turn from coarse to fine in grain size, which may also reflect a small-scale retrogradation process. The source supply is gradually weakened, and the sedimentary structure can be seen as flame structure and Bouma sequence.

# 5. Chang 7 Sedimentary Facies Distribution Characteristics and Oil Control Law

## 5.1. Profile distribution law

After the Ordos Basin suffered from the strong compression from the southwest and the vertical uplift of the northeastern margin, the center of the lake basin migrated and evolved from northeast to southwest during the sedimentary period of the Yanchang Formation. The source direction of the Chang 7 sedimentary period is mainly from the northeast and southwest. The NE-SW source direction profile is selected to study the distribution of sedimentary facies. The sedimentary facies profile of Z512 well-Xx12 well in Chang 7 section of Zhidan area reveals that the delta front subfacies are developed in the northeast of the study area, and the semi-deep lake-deep lake subfacies are developed in the southwest.

During the sedimentary period of Chang $7_3$, delta front subfacies were developed in well Xx12, and semi-deep lake-deep lake subfacies were developed in well Z512-Z57. The water depth in the southwest-northeast direction gradually becomes shallower, and the lithology gradually changes from black shale to gray-black mudstone. Turbidite is more developed, with a thickness of about 0.5~2 m, and sand body connectivity is poor. The lithology of the first line of the F247-Xx12 well in the northeast is mainly argillaceous siltstone and silty mudstone, and the sliding-slump rock is mostly developed. The thickness of the sand layer is about 5~8 m.

During the Chang $7_2$ sedimentary period, the delta front subfacies was expanded compared with the Chang $7_3$ sedimentary period. The well control range was expanded from Xx12 well to F231 well, and the F310 well-Z512 well still developed semi-deep lake-deep lake subfacies. The lithology in the southwest is mainly argillaceous siltstone and mudstone, and the gravity flow sand bodies such as sandy debris flow, sliding-slump rock and turbidite are developed. The lithology of the northeastern part is mainly siltstone and fine sandstone, and the sand body connectivity is good.

During the Chang $7_1$ sedimentary period, the delta front subfacies was further expanded compared with the Chang $7_2$ sedimentary period, and the well control range was expanded to the F310 well. The lake basin gradually shrinks, and the area of semi-deep lake-deep lake area gradually shrinks. Wells F310-Z512 still develop semi-deep lake-deep lake subfacies, and sandy debris flow and sliding-slump rock are developed. The thickness of the sand layer is about 5~15 m and 3~8 m, respectively, and the sand body connectivity is good.

## 5.2. Plane distribution and oil control

### 5.2.1. Chang 73 sub-segment

During the sedimentary period of Chang $7_3$, the Zhidan area is mainly semi-deep lake-deep lake deposition. The delta front is limited in the northeast, mainly composed of five large underwater distributary channels, and the sand ratio is as high as 70%~90%. The semi-deep lake-deep lake deposits in the southwest direction are mainly developed in the Shunning-Yongning-Wubao area. The thick mudstone sand ratio is generally 30%, in which the sandy debris flow, slip-slump rock and turbidite sand ratio are 50%~70%, 30%~50%, 30%~60%, respectively. The sliding-slump rock is mainly distributed under the slope break zone of the delta front, and then the turbidite appears forward, and the sand body is scattered as a whole. Some exploratory wells in the gravity flow sedimentary sand body development area and the underwater distributary channel sedimentary area have obtained industrial oil flow, which is a favorable area for shale oil exploration.

### 5.2.2. Chang 72 sub-segment

During the sedimentary period of Chang $7_2$, the lake basin in Zhidan area shrank, which was significantly reduced compared with the sedimentary period of Chang $7_3$. The sedimentary area of the delta front gradually expands to the center of the lake basin, and the sand ratio is 70%~90%. The central part of the lake basin is still dominated by semi-deep lake-deep lake deposits. The scale of gravity flow sedimentary sand bodies is larger and better connected than that of Chang $7_3$ period. The turbidite facies is less developed than that of Chang $7_3$ period, and a large number of sliding-slump rocks and sandy debris flow sedimentary sand bodies are mainly seen. The lithology of the sand body is mainly fine sandstone, siltstone and argillaceous siltstone, and the extension length of the sand body is 10-20 km. The number of industrial oil flow wells is more than that of Chang $7_3$ sedimentary period. Underwater distributary channels and gravity flow sedimentary areas are developed, with multiple reservoir enrichment areas and poor plane connectivity.

### 5.2.3. Chang 71 sub-segment

The sedimentary period of Chang $7_1$ is dominated by delta front deposition, and the underwater distributary channel sand body extends to the lake in the form of bird feet on the plane, and the sand ratio is 70%~90%.The semi-deep lake-deep lake facies is limitedly distributed in the southwest of the study area, with Danba Town as the dividing line. The width and scale of the delta front channel are longer than that of the $7_2$ period, and the multi-stage channel is superimposed and bifurcated, and then the confluence extends to the southwest. The thickness of the sand body is generally 10~20 m, and the sand ratio is 30%~50%. The industrial oil flow wells in the Chang $7_1$ sedimentary period increased significantly compared with the Chang $7_3$ and Chang $7_2$ periods, and most of them were distributed in the delta front subfacies, mainly concentrated in the north-central, southwest and southeast of Zhidan area, and the enrichment area was mainly distributed in the north of Jinding area. There are also many industrial oil flow wells in the gravity flow sedimentary sand body development zone, which is worthy of exploration attention.

# 6. Summary

(1) The sedimentary facies types of Chang 7 member of Yanchang Formation in Zhidan area of Ordos Basin are mainly delta front subfacies and semi-deep lake-deep lake subfacies, which are subdivided into underwater distributary channel, interdistributary bay, sliding-slump rock, sandy debris flow, turbidite and semi-deep lake-deep lake mud microfacies.

(2) During the sedimentary period of Chang $7_3$, the lake basin reached its peak, and the delta front sedimentary sand bodies were not developed. A small amount of turbidite, sliding-slump rock and sandy debris flow sedimentary sand bodies were seen, mainly developing semi-deep lake-deep lake mud microfacies. During the sedimentary period of Chang $7_2$, the scale of delta front sand body and lake bottom gravity flow sedimentary sand body is equivalent. During the sedimentary period of Chang $7_1$, the delta front underwater distributary channel was the main channel, and the gravity flow sand body at the bottom of the lake was small, mainly distributed in the southwest.

(3) The gravity flow and underwater distributary channel sand bodies developed in the Chang 7 sedimentary period are widely distributed, and the industrial oil flow wells are distributed in a large area. The oil production of gravity flow sedimentary sand bodies is generally higher than that of underwater distributary channel sedimentary sand bodies, and the oil production of Chang $7_1$ sub-section is higher than that of $7_2$ and $7_3$ sub-sections. Gravity flow sedimentary sand bodies and underwater distributary channel sand bodies are favorable sedimentary types for shale oil and tight oil exploration.

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