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Retraction

Retracted: Characteristics of Sedimentary Microfacies of Late Triassic Yanchang Formation in North-Central Ordos Basin

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This article has been retracted by Hindawi, as publisher, following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of systematic manipulation of the publication and peer-review process. We cannot, therefore, vouch for the reliability or integrity of this article.

Please note that this notice is intended solely to alert readers that the peer-review process of this article has been compromised.

Wiley and Hindawi regret that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

References

[1] J. Wei, F. Li, S. Zhang, H. Cheng, Q. Qin, and D. Cadasse, "Characteristics of Sedimentary Microfacies of Late Triassic Yanchang Formation in North-Central Ordos Basin," *Journal of Chemistry*, vol. 2022, Article ID 1513503, 10 pages, 2022.

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Research Article

Characteristics of Sedimentary Microfacies of Late Triassic Yanchang Formation in North-Central Ordos Basin

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Sedimentary microfacies refer to the smallest unit with unique rock structure, structure, thickness, rhythm, and other sedimentary characteristics and certain plane configuration rules in the subfacies zone. Sedimentary microfacies research is the most basic sedimentary unit formed in the same or basically the same sedimentary background. Sedimentary microfacies marks are the key to the division of sedimentary microfacies. If we cannot find effective marks, we cannot correctly divide sedimentary microfacies. These marks are mainly obtained from detailed observation of cores. On the premise of fully understanding the regional tectonic background of the study area, the sedimentary facies and sedimentary subfacies types within the oilfield control range are determined. In this study, the single-well facies and profile facies are deeply analyzed by observing and describing the cores of Chang 2 reservoir group in Huangjialing, north-central Ordos Basin, and comprehensively utilizing the data of coring, logging, and core analysis and testing. The basic sedimentary characteristics, types of sedimentary facies and microfacies, and plane distribution of sedimentary facies in this area are systematically studied. The results show that there are mainly three microfacies: underwater distributary channel, natural dike, and distributary bay. Among them, the microfacies of the underwater natural dike are relatively undeveloped, mainly the microfacies of underwater distributary channel and underwater distributary bay. These studies have important practical significance for the later exploration of oil and gas in Ordos Basin.

1. Introduction

In the Late Triassic, Ordos Basin was an asymmetric depression basin with gentle in the east and steep in the west. The main oil and gas resources of Yanchang formation were distributed in the eastern gentle slope zone. The gentle slope zone has flat terrain, shallow water body, and wide distribution area. The density of river water carrying a large amount of sediment is greater than that of lake water. After entering the lake, it still maintains a high flow rate and flows forward along the flat lake bottom for a long time, thus forming a wide delta sedimentary front. Sedimentary microfacies are four-level facies that are divided into sedimentary facies based on the sedimentary environment, combined with hydrodynamic conditions and sedimentary characteristics [1]. Sedimentary microfacies can not only be used to characterize paleontological and petrological characteristics but also can be used as a marker to divide rock types. The study of sedimentary microfacies begins with the study of carbonate rocks. The discovery of large carbonate reservoirs has aroused a worldwide upsurge in the study of carbonate rocks by scholars [2, 3]. In terms of diagenetic model, depositional environment, depositional model, etc., it has gradually penetrated into the research field of terrigenous clastic rocks. Through comprehensive research on carbonate rock microfacies, it is found that both dolomite and limestone can be used as good reservoirs for oil and gas [4, 5]. This important theoretical significance and guiding significance for exploration and development practice work have promoted the research on carbonate rock microfacies [6]. According to the characteristics of different layers of sedimentary bodies, Chinese scholars divide sedimentary facies into subfacies and further subdivide them into "sedimentary microfacies" and even "microfacies" on this basis. Different types of sedimentary microfacies show different frequencies and different distribution horizons on the stratigraphic section. Therefore, the study and analysis of sedimentary microfacies can be used to restore the paleogeographic environment during the depositional period and deduce the change process of the depositional environment [7–9].

The Danish geologist was the first person to introduce facies as a geology concept into the literature related to geology, emphasizing that facies refer to a certain geological period showing the general appearance of a certain part of the Earth's surface [10]. The Swiss geologist used the concept of sedimentary facies in sedimentary rocks in the mid-17th century, extending the meaning of facies to sedimentology. The performance of different aspects is different, and the change is the essence of sedimentary facies. Since then, the geoscience community has recognized and used this concept. The concept of phase has different meanings with the continuous development and evolution [11–13]. When it represents lithological feature units or biological assemblages, it refers to lithofacies or biological facies, such as shale facies and graptolite facies. When it represents the product of sedimentation, it is the interpretation of the cause of rock formation, such as platform facies. When it represents the product of tectonic movement, it refers to sedimentary formations, such as molasse facies. When it represents the performance of the depositional environment, it refers to sedimentary facies, such as delta facies [14–16]. Chinese sedimentologist proposed in the middle of the 20th century that sedimentary facies have stratigraphic and paleogeographic significance, because it is a combination of depositional environments and should be reflected in the corresponding time and space [17].

On the one hand, sedimentary microfacies are developing in depth, with a higher and higher degree of refinement and a stronger degree of comprehensiveness. Instead of only using logging and seismic data to analyze sedimentary facies and delineate facies zones in the past, researchers use various kinds of information for multi-angle prediction [18]. On the other hand, there is still a certain gap between China and the international level, which is mainly reflected in the quantitative aspect of research. China has taken a huge step from the uncertainty of the past to semiquantitative [19, 20]. Compared with the international advanced level, which is mainly based on quantitative research, there is still a lot of room for improvement in China. Technologies such as three-dimensional modeling led by computer technology and statistical quantification of mathematical methods are powerful means of quantitative research. In this study, through the observation and description of the core of the Huangjialing Chang 2 oil formation in the north-central Ordos Basin, the basic sedimentary characteristics, sedimentary facies and microfacies types, and the planar distribution of sedimentary facies were systematically studied [21].

2. Geological Background

Ordos Basin is one of the giant energy basins in China, which is rich in oil, natural gas, and coal resources. Today, the basin is surrounded by orogenic belts in different periods, forming a distribution pattern of "basin" and "mountain." It is connected to Yinshan Mountain in the north, Qinling Mountain in the south, Luliang Mountain in the East, and Helan Mountain in the west. The basin is adjacent to the Hetao Basin across the Wulanger bedrock uplift in the north, facing the Weihe River Basin in the south, the Jinxi flexure fold belt in the East, and the Luliang Uplift in the East, and facing Liupanshan and Yinchuan basins in the west through the overthrust structural belt. The outline is rectangular. It crosses the five provinces of Shaanxi, Gansu, Ningxia, Mongolia, and Shanxi and is located on the western edge of the North China Craton, with an area of $25 \times 10\%\ km^2$.

The Upper Triassic Yanchang Formation in the Ordos Basin is a set of fluvial-lake facies terrigenous clastic rock sedimentary systems accumulated during the continuous depression and stable subsidence of the basin. It is a set of major oil-bearing rock series in the basin. The evolution process of this large inland freshwater lake basin includes formation and development to extinction. During the depositional period of the Yanchang Formation, the Ordos Basin has the characteristics of large area, wide water area, shallow depth, flat terrain, and weak segmentation [22]. The Yimeng uplift, the western Jinxi flexural fold belt, the Weibei uplift, and the western margin thrust developed around the lake basin. Therefore, the provenance is abundant and the sedimentary thickness is large. The axial direction of the basin is northwest-southeast, and the sedimentary center of the lake basin is south of the 38° latitude line. The distribution of facies belts is slightly ring-shaped, in which the lake shoreline of the southwest margin is in the Shigouyi-Pingliang-Yongshou area, and near-source and near-shore subaqueous fan deposits are developed along the lake shoreline [23]. The northern lake shoreline may move southward continuously from the Wushenqi-Jingbian-Hengshan-Zizhou area (Figure 1), and a series of lake delta deposits developed along the lake shoreline strongly advancing toward the lake. The lake basin is asymmetric in shape, steep in the west, and gentle in the east.

Alluvial fan, fan delta, fluvial, braided river delta, meandering river delta, and lacustrine deposits are widely developed in Ordos Basin in Late Triassic. The alluvial fan and delta are related to the steep basin margin. Braided river delta is related to the steep gradient of basin margin. The meandering river delta is related to the gentle slope depression type boundary, which is characterized by river sedimentation and lake sedimentation.

3. Results and Discussion

3.1. Types of Sedimentary Microfacies. Sedimentary system analysis is one of the most important advances in modern

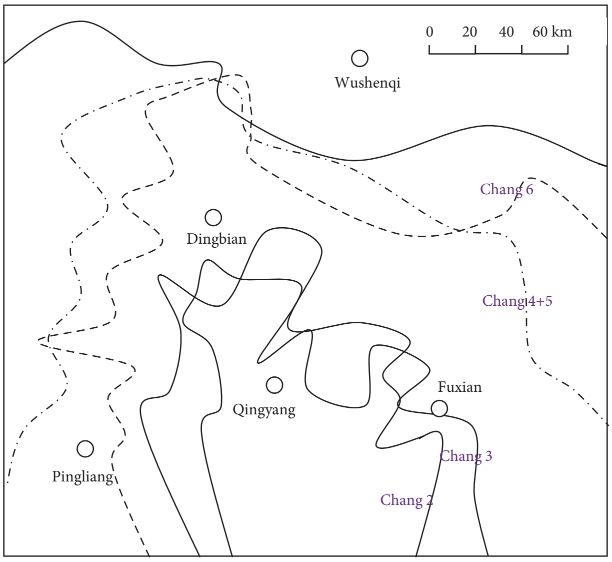

Figure 1: Schematic diagram of late Triassic Lake shoreline migration in the central and northern Ordos Basin.

sedimentology. Since the 1960s, sedimentologists have begun to apply the principles of sedimentary systems to analyze sedimentary basins. The so-called sedimentary system refers to the aggregation of sedimentary facies related to the action. We can also understand it as a three-dimensional stratigraphic unit composed of genetically related sedimentary facies in space. Its meaning includes three-dimensional combination of supply source, action process, and geographical environment.

The Huangjialing Chang 2 sand body is composed of light gray, light gray-green fine sandstone, silt sandstone, and sandstone with a large thickness of single layer due to sufficient provenance supply, fast deposition rate, and large superimposed thickness of sand layers. It is composed of gravel-coarse sandstone, mudstone, and argillaceous siltstone, reflecting the characteristics of underwater distributary channels with slow and stable channel migration, forming a relatively characteristic thick and massive bedding fine sandstone facies. There are four types of rhythm in the reservoir sand body: homogeneous, compound rhythm, positive rhythm, and inverse rhythm. The shape of SP curve is mainly box-shaped and box funnel-shaped (90.6%), and a few are bell-shaped.

The rock has low structural maturity and low compositional maturity, sandstone sorting is moderate, roundness is poor, the clastic particles are mostly subcircular-subangular, and the grain size is mainly fine-grained sandstone, followed by medium grains. The particle size probability curve is mainly composed of jumping and suspension (Figures 2 and 3), indicating that during the process of flowing water, the detrital particles are obviously transformed by the action of lake waves. This kind of transformation can form a wide range of particle size distribution, reflecting the delta sedimentary characteristics of the underwater distributary channel of the front.

The delta front is the main underwater part of the river entering the lake, the most active place of delta deposition, the development zone with concentrated sand layers in the delta, the most important skeleton part of the delta, the coastal shallow lake gentle slope zone below the estuary, and the river lake interaction zone.

The research results of regional sedimentary facies show that the sedimentary period of Chang 2 Member is the period of the gradual disappearance of lake basins. The sedimentary facies type of Chang 2 Member in Huangjialing area of Zhiluo oilfield is lacustrine-delta facies, and the sedimentary subfacies is dominated by delta front subfacies. The hydrodynamic conditions are moderate to weak, and it has a certain wave transformation effect and river effect.

On the basis of the previous regional sedimentary background analysis, comprehensive analysis was carried out according to various sedimentary facies markers such as reservoir coring well lithology, sedimentary structure, sequence characteristics, grain size characteristics, and electrical survey curve shape. The sedimentary microfacies of the small layer and single layer of the oil layer group are divided into three kinds of microfacies. There are mainly three types of microfacies developed: underwater distributary channel, natural levee, and interdistributary bay. Among them, the underwater natural levee microfacies is relatively undeveloped, and the underwater distributary channel and underwater interdistributary bay microfacies are mainly developed.

The underwater distributary channel is the underwater extension of the distributary channel in the delta plain. The sand body of underwater distributary channel has the characteristics of normal cycle of coarse at the bottom and fine at the top in the longitudinal section. There is a scouring surface at the bottom, and mudstone and gravel bearing sandstone are often developed. Upward, it is thick-bedded medium-fine sandstone, intercalated with thin layers of siltstone and argillaceous siltstone and silty mudstone in the distributary bay.

The subaqueous distributary bay is located between the subaqueous distributary channels and is dominated by fine-grained sediments. The lithology is thick gray black silty mudstone, argillaceous siltstone, siltstone, and mudstone with thin layer of gray and gray-green fine sandstone. Plant leaf fossils are developed in mudstone. Sand ripple cross-bedding is developed in siltstone, with carbon debris and vertical wormholes. The natural potential curve of the distributary bay is low and flat, the natural gamma curve is medium and high value, showing a tooth shape, and the resistivity curve is medium and low value.

3.2. Analysis of Sedimentary Microfacies Characteristics

3.2.1. Rock Types and Characteristics. Color is one of the important macroscopic characteristics of sedimentary rocks, which is closely related to its own composition and formation environment. There is a lack of coring data in the study area, but judging from the logging data and the core data in the adjacent area, the main medium and fine sandstones are mainly gray, gray-green, and light gray; the siltstones are mostly dark gray; and the mudstones are black.

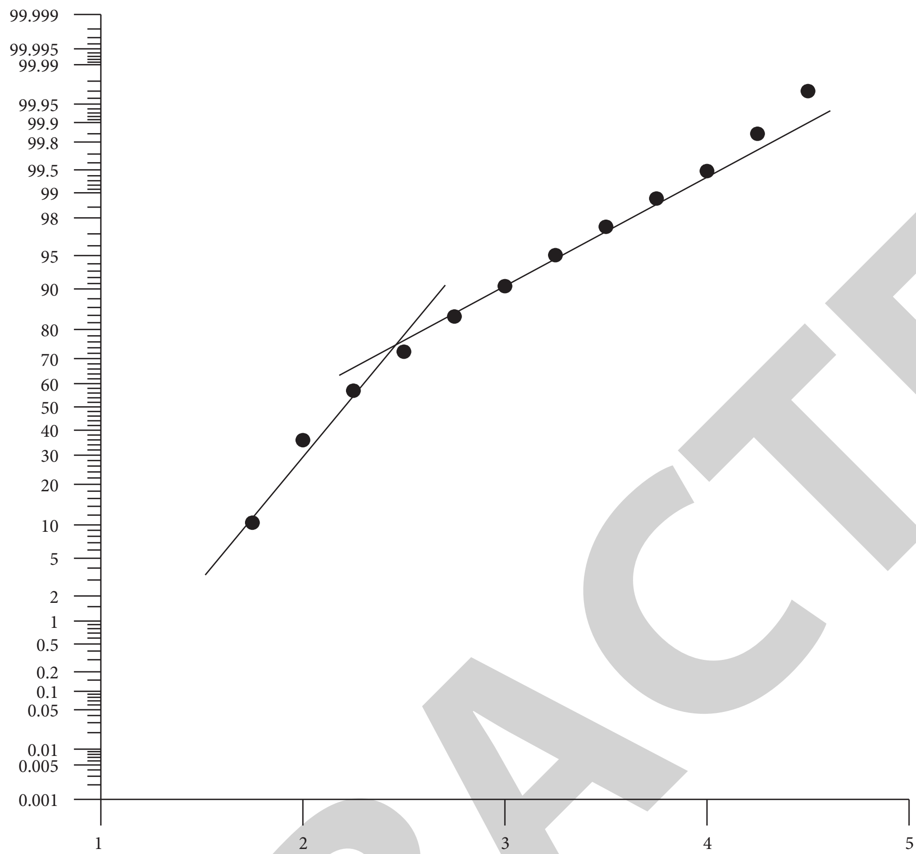

Figure 2: Probability curve of particle size distribution in Well Lu 203.

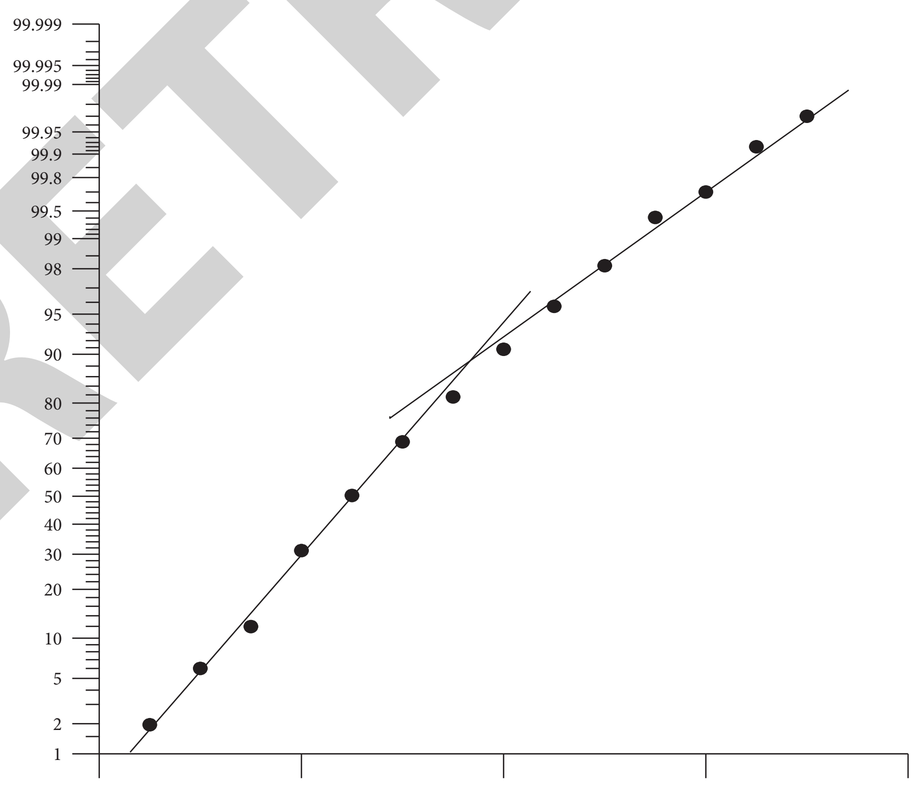

Figure 3: Probability curve of particle size distribution in Well Lu 29.

The main factors affecting the color of sandstone and mudstone are the content of ferrous iron, ferric iron, and organic matter, which are related to the relative stability of the water body and the environment of the redox medium. Generally speaking, the higher the content of organic matter in the rock (especially in the mudstone), the darker the color. The rocks are purple-red. The higher content of ferrous iron and organic matter generally indicates a reducing depositional environment, while the higher content of ferric iron indicates an oxidative depositional environment. The data of the study area and its adjacent areas show that the color of the Yanchang Formation indicates that the study area is a weak reduction-reduction environment. The characteristics of the rock components in the study area are generally high quartz content and high feldspar content. The content of interstitial material is between 8% and 16%, the components are mainly argillaceous and calcareous, and the cements are mainly chlorite, kaolinite, and calcite.

The early sedimentary stage of Yanchang formation is the formation stage of lakes, the fluvial sedimentation is developed, and the delta is in the construction stage of gradual development. Sandstone is the main rock type of terrigenous clasts, and its clastic material mainly comes from the products of mechanical crushing of parent rock, which is an important indicator of material source. The statistics of rock components in different areas show that the early sedimentary period of Yanchang formation is dominated by arkose.

3.2.2. Sedimentary Structural Markers. Sedimentary structure refers to the overall characteristics of the spatial distribution and arrangement of the components of sedimentary rocks, or the sum of the mutual arrangement of the particles of the rocks. The structures formed in the process of sediment formation and before sedimentation consolidation and diagenesis are called primary structures, such as bedding and bedding structures. The structures formed after consolidation diagenesis are secondary structures, such as sutures. The sedimentary structures in clastic rocks, especially the primary sedimentary structures of physical origin, can best reflect the hydrodynamic conditions in the process of sediment formation. The sedimentary structures preserved in the study area mainly include flow-derived structures, syngenetic deformation structures, and biogenic structures, which are the most important signs for analyzing and judging sedimentary facies.

(a) The Structure of Flow Genesis

① Horizontal bedding: in mudstone and silty mudstone, the thickness of the single layer is small, the laminae are parallel to each other and parallel to the layer, and the bedding sees fine plant debris and abundant mica flakes, often formed under the wave base or in the low-energy environment. In the low flow state and in the case of insufficient material supply, it is mainly formed by the slow vertical accumulation of suspended matter. This kind of sedimentary structure is mainly developed in the delta front and the interdistributary bay of the plain, underwater natural embankment, and prodelta shallow lakes (Figure 4).

② Parallel bedding: the lithology is dominated by medium- and fine-grained sandstone. The thickness of the laminae is generally 0.5 to 1.0 cm. It consists of straight continuous or intermittent textures that are parallel to each other and parallel to the layers. The texture can be plant debris, cuttings or dark minerals, and colors. The difference shows that it is often formed under the hydrodynamic conditions of shallow water and rapid flow, and is mainly found in the estuary sand bar or underwater distributary channel sediments with strong hydrodynamic force.

③ Plate cross-bedding: the lithology is composed of gray-light gray medium- and fine-grained sandstone. The main feature is that the large-scale stratum is composed of straight bedding at the upper and lower interfaces, which is plate-shaped. The stratum is 15–20 cm, and the thickness is relatively stable. On the left and right, the texture is continuous and intermittent. There are fine carbon chips and plant debris on the lamina layer. The lamina can converge to the bottom surface of the layer system, and the included angle is often less than 10°. It is formed by the migration of sand waves, and this area often occurs in the sedimentary environment of delta front estuarine sand bars and underwater distributary channels.

④ Trough-shaped cross-bedding: the lithology is fine sandstone and silty sandstone, and small trough-shaped cross-bedding is developed. Small charcoal debris, plant debris, and occasionally small scour surfaces, generally migrated from large asymmetric tongue-shaped or crescent-shaped sand slopes, mostly formed in underwater distributary channels and estuary sand bars in the delta front.

⑤ Sand grain cross-bedding: it is composed of a series of laminae obliquely crossing the interface of the layer system. The relationship between the laminae and the layer system can be combined by overlapping, interlacing, and cutting. Cross-bedding is caused by the flow of sedimentary media. When the flow velocity is constant, a series of sand waves can be generated in the sand bed. The downstream migration of sand waves forms an oblique layer system composed of a series of laminae on the side of the steep slope. The laminae trend indicates the direction of media flow. The layers are parallel to each other or cut each other to form cross-bedding of different shapes. It mainly occurs in siltstone and argillaceous siltstone. It is a small cross-bedding of multilayered series. The lower interface of the layered series is microwave, the laminar layer is irregular, discontinuous, or continuous, and the fine layer is inclined to one side. Fine plant debris, charcoal, and abundant mica flakes are seen on the bedding surface and often coexist with parallel bedding, plate

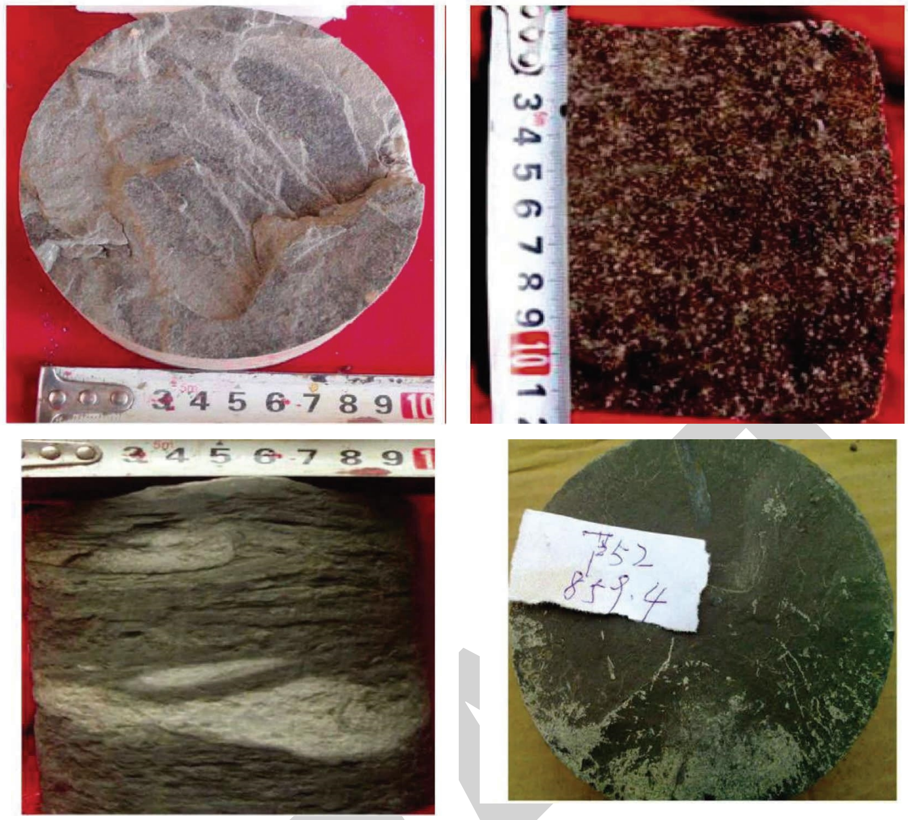

Figure 4: Main sedimentary structure of Chang 2 oil reservoir group. (a) Parallel-bedded fine sandstone. (b) Tabular cross-bedded fine sandstone. (c) Gray-black mudstone intercalated with fine sandstone lens. (d) Horizontal bedding mudstone, with carbonized plant fossils.

bedding, and small cross-bedding. It is formed by sand grain migration and is mainly formed in environments with weak hydrodynamic conditions, such as interdistributary bays in delta fronts, underwater natural dikes, far sand bars, and prodeltas.

⑥ Lenticular layering: the lens sand of lenticular bedding is of silt grade. It is formed when the hydrodynamic conditions are weak, the supply of sand is insufficient, and the supply, deposition, and preservation of mud are more favorable than those of sand.

⑦ Wave bedding: it is composed of many undulating fine layers overlapped together and formed under oscillating hydrodynamic conditions or wind force. The formation of wavy bedding generally requires a large amount of suspended matter deposition, and the deposition rate is greater than the erosion rate of flowing water so that continuous fine layers can be preserved. Commonly found in fine sandstone and siltstone, it is a small bedding; the laminae are discontinuous or continuous wave or microwave; and mainly continuous wave, fine charcoal, plant debris, and abundant mica are seen on the bedding surface. It is more common in sedimentary environments such as estuarine sand bars and far-estuarine sand bars.

⑧ Massive bedding: massive bedding developed in large-scale distributary channel deposits, representing a rapid, continuous, uniform, and stable depositional process. It is mainly medium-fine sandstone, the internal material is uniform, and there is no differentiation in composition and structure.

⑨ Scrub surface: it is a layered structure generated under high flow conditions. Due to the small volume of the core, only a gentle scouring surface can be seen on the core. The scouring surface mostly appears at the bottom of the underwater channel, where a large amount of redeposited mud is common.

(b) Syngenetic Deformation Structure

The syngenetic deformation structure is a kind of sedimentary structure in the sedimentary layer caused by the action of gravity and the action of sediment liquefaction flow during the time interval between the deposition of the sediment and the consolidation of the diagenesis. The area mainly occurs in the interbedded lithology of fine sandstone, siltstone, and silty mudstone, including slump deformation structure, wrapping bedding, and sand pillow sand ball structure. They occur in estuarine sand bars and the upper parts of underwater distributary channels.

① Wrapping bedding: it is a bedding crumpling phenomenon within a layer, which is composed of continuous open "synclines" and tight "anticlines," but the layers are continuous. It is generally limited to bedding deformation within a layer and does not involve the upper and lower layers. It is mainly caused by the distortion of the thin layer caused by the lateral flow in the liquefied layer within the sedimentary layer. Most of the enveloping bedding in this area occurs in the estuary sand bar and the upper part of the underwater distributary channel in the delta front.

② Slump deformation structure: most of the slump-deformed structures are formed by the continuous sliding of the encapsulated bedding. The laminae in the sedimentary layers appear discontinuous and disorderly accumulation, and even sediment fragments appear. Mud tearing debris is common in sandstones. The slump deformation structure is generally produced with rapid deposition. It is a good sign of underwater landslides and is mostly distributed in the delta fronts with slopes.

③ Ball pillow structure: this kind of structure often appears in sand and mud interbeds, and refers to the ellipsoid or pillow-shaped blocks formed by the sandstone layer breaking and sinking into the mudstone. Only a ball-pillow structure about ten centimeters in size can be seen in the core. It is found in predelta or interdistributary bay environments.

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(c) Biogenic structure: it is mainly a wormhole structure, which is a tubular burrow dug by organisms in the coastal zone to feed on suspended organisms and avoid the impact of water waves. It is usually straight and tubular, indicating an underwater environment near a lake shoreline.

3.2.3. Logging Facies Signs. Different sedimentary microfacies have different logging response forms; in other words, different logging response forms are the embodiment of different sedimentary microfacies. The so-called logging facies refers to the sum of the logging responses that characterize the formation characteristics, and this logging response feature is different from other surrounding logging responses. Therefore, logging facies analysis is an indispensable aspect of sedimentary facies research, and sedimentary facies can be reshaped by logging facies analysis.

The elements that make up the log facies are all log responses, including not only qualitative aspects (characteristics of the curve) but also quantitative aspects (values of logging parameters). The content of logging facies analysis includes the selection of logging response sequence, the analysis of logging response curve characteristics, and the analysis of logging facies characteristics. According to the combination characteristics of formation lithology characteristics, sedimentary characteristics and logging response curve, and its resolution, it can be seen that the natural gamma curve is mainly selected in the study area. The log facies analysis is performed with the supplemented logging response sequence, and the effect is good. The characteristics of the logging response curve include abnormal amplitude, smoothness, convergence of tooth centerline, curve shape and top-bottom contact relationship, etc. They reflect the lithology, grain size, shale content, and vertical changes of the formation from different aspects.

① Amplitude: the amplitude of the logging curve (such as natural potential and natural gamma curve) can reflect the grain size and shale content of the sediment to a certain extent, so as to infer the hydrodynamic strength of the sedimentary medium. It is divided into three types: low, medium, and high. The Yanchang Formation in the study area is dominated by medium and low amplitudes, especially with low amplitudes accounting for the largest proportion, which is related to the finer sediment particle size. The sandstone in the study area is mainly composed of fine sand and medium-fine sand, with high content of silt and mud.

② Contact relationship: it refers to the top and bottom shape of the logging curve of a single-layer sand body, which can reflect the changes of hydrodynamic conditions and sediment supply conditions in the initial and final stages of sedimentary deposition to a certain extent.

The abrupt type shows the drastic changes in hydrodynamic conditions and sediment supply before and after the deposition of sedimentary bodies, and can be further divided into top abrupt type and bottom abrupt type. Mutant contacts are well developed in this region; in particular, bottom mutations are more common.

Corresponding to the sudden change, the gradual change indicates the gradual change of the hydrodynamic conditions and sediment supply conditions in the sand body deposition process, and can be further divided into top gradual change and bottom gradual change. The top gradual change indicates the gradual change of the hydrodynamic strength of the sedimentary medium. The bottom gradient type is caused by the gradual increase of hydrodynamic force and/or the gradual increase of relative coarse-grained sediment supply.

③ Smoothness of the curve: the smoothness of the logging curve can reflect the sediment sorting to a certain extent. It can be divided into three types: smooth, microtooth, and dentate. The latter two in the Huangjialing well area; in particular, the microtooth is more common, indicating that the sandstone has a moderate degree of sorting.

④ The shape of the curve: the shape of the logging curve (including single layer or combined shape) is one of the important contents of logging facies research, and it is often divided into bell-shaped, box-shaped, funnel-shaped, and some combined shapes. The box shape reflects the relatively stable deposition process of water energy, and there is a continuous and stable supply of sediment; the bell shape and the funnel shape indicate that the deposition process has water energy from strong to weak and from weak to strong, respectively. The common logging curve shapes in the study area are as follows:

(a) Bell-shaped. The amplitude is high in the middle and lower parts of the curve, and the amplitude in the upper part is low. From bottom to top, the amplitude of the curve decreases, showing a bell shape with a wide bottom and a narrow top, indicating that the supply of sediment is reduced and the hydrodynamic force of the sedimentary medium is weakened. This shape is relatively developed in the Chang 2 oil-bearing formation in the Huangjialing well area, and microdentate formation is common, with a gradual relationship upward and abrupt contact downward. Mud-gravel, muddy strips, and scour structures are sometimes seen at the bottom of the sandstone, and parallel bedding or plate-like cross-bedding are common inside, which is a reflection of the positive grain sequence characteristics of distributary river deposits.

(b) Bell-box combination. The bell-box combination is a relatively well-developed logging curve shape type for the Chang 2 oil layer group in the study area. It is a box-shaped combined curve, with abrupt contact at the bottom and a gradual relationship at the top.

(c) Box-shaped. The curve has a relatively high amplitude and a large width, and the top and bottom fluctuations are basically the same, indicating that the sediment particle size is relatively coarse, with continuous strong hydrodynamic conditions and relatively stable and sufficient provenance supply. The box-shaped curve of the sand bodies in this area is dominated by medium and low amplitudes, and the sedimentary grain size is relatively fine (fine sand), mainly channel sediments, smooth, and toothed, and the top and bottom are basically showing abrupt contact relationship.

(d) Funnel-shaped. The amplitude in the middle and upper parts of the curve is relatively high, and the amplitude in the downward direction gradually decreases. The funnel-shaped curve in this area is rare.

4. Conclusion

Through the observation and description of the cores of Chang2 oil formation in Huangjialing, central and northern Ordos Basin, the study comprehensively analyzed the single well facies and profile facies by using coring, logging, and core analysis and testing data, and systematically studied the basic sedimentary characteristics, sedimentary facies, and microfacies types and the planar distribution of sedimentary facies in this area. The results are as follows:

(1) According to the comprehensive analysis of various sedimentary facies markers such as reservoir coring well lithology, sedimentary structure, sequence characteristics, grain size characteristics, and electrical survey curve shape, it is considered that the sublayer and single layer of the Chang 2 oil layer group in this area are the most important. The sedimentary microfacies is divided into 3 kinds of microfacies. There are mainly three types of microfacies developed: underwater distributary channel, natural levee, and interdistributary bay. Among them, the underwater natural levee microfacies is relatively undeveloped, and the underwater distributary channel and underwater interdistributary bay microfacies are mainly developed.

(2) The color of the extension group indicates that the study area is a weak reduction-reduction environment. The characteristics of the rock components in the study area are generally high quartz content and high feldspar content. The sedimentary structures in clastic rocks, especially the primary sedimentary structures of physical origin, can best reflect the hydrodynamic conditions in the process of sediment formation. The sedimentary structures preserved in the study area mainly include flow-derived structures, contemporaneous deformation structures, and biogenic structures.

(3) According to the combination characteristics of formation lithology characteristics, sedimentary characteristics and logging response curve, and its resolution, it can be seen that the natural gamma curve is mainly selected in the study area, and combined with the natural potential curve, the resistivity and acoustic time difference curve, the log facies analysis is performed with the supplemented logging response sequence, and the effect is good.

Data Availability

The figures used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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References

[1] C. T. Perry and A. Berkeley, "Intertidal substrate modification as a result of mangrove planting: impacts of introduced mangrove species on sediment microfacies characteristics," *Estuarine, Coastal and Shelf Science*, vol. 81, no. 2, pp. 225–237, 2009.

[2] X. Ma and S. Guo, "Comparative study on shale characteristics of different sedimentary microfacies of late permian longtan formation in southwestern Guizhou, China," *Minerals*, vol. 9, no. 1, p. 20, 2018.

[3] X. Wei, J. Liu, and J. Liu, "Study on sedimentary microfacies and impact on development of Chang 6 1 reservoir in Shijiapan area, Ordos Basin," *Northwestern Geology*, vol. 51, no. 4, pp. 255–262, 2018.

[4] C. T. Perry, A. Berkeley, and S. G. Smithers, "Microfacies characteristics of a tropical, mangrove-fringed shoreline, Cleveland Bay, Queensland, Australia: sedimentary and taphonomic controls on mangrove facies development," *Journal of Sedimentary Research*, vol. 78, no. 2, pp. 77–97, 2008.

[5] J. L. Wilson, "Microfacies and sedimentary structures in deeper-water lime mudstones," *AAPG Bulletin*, vol. 51, no. 3, pp. 485-486, 1967.

[6] Y. Wang, D. Dong, X. Li, J. Huang, S. Wang, and W. Wu, "Stratigraphic sequence and sedimentary characteristics of lower silurian longmaxi formation in sichuan basin and its peripheral areas," *Natural Gas Industry B*, vol. 2, no. 2-3, pp. 222–232, 2015.

[7] X. Lu, D. Sun, X. Xie et al., "Microfacies characteristics and reservoir potential of triassic Baikouquan Formation, northern Mahu sag, Junggar Basin, NW China," *Journal of Natural Gas Geoscience*, vol. 4, no. 1, pp. 47–62, 2019.

[8] A. Seyrafian, "Microfacies and depositional environments of the Asmari Formation, at Dehdez area (a correlation across central Zagros basin)," *Carbonates and Evaporites*, vol. 15, no. 2, pp. 121–129, 2000.

[9] M. H. Basyoni and M. A. Aref, "Sediment characteristics and microfacies analysis of Jizan supratidal sabkha, Red Sea coast, Saudi Arabia," *Arabian Journal of Geosciences*, vol. 8, no. 11, pp. 9973–9992, 2015.

[10] C. Sun, M. Hu, X. Luo, and D. Gao, "High-frequency sequence and sedimentary microfacies evolution characteristics of the 3rd member of the Ordovician Yingshan formation in the Gucheng area, Tarim Basin, NW China," *Arabian Journal of Geosciences*, vol. 14, no. 22, pp. 2433–2519, 2021.

[11] R. Zhang, J. Wang, Y. Ma, G. Chen, Q. Zeng, and C. Zhou, "Sedimentary microfacies and palaeogeomorphology as well as their controls on gas accumulation within the deep-buried Cretaceous in Kuqa depression, Tarim Basin, China," *Journal of Natural Gas Geoscience*, vol. 1, pp. 45–59, 2016.

[12] Y. Liu, X. Yu, S. Li, W. Du, M. Li, and S. Li, "Characteristics and evolution of sedimentary microfacies of Chang $6-4+5$ layer in the northern area of western Mahuang mountain," *Earth Science Frontiers*, vol. 16, no. 4, pp. 277–286, 2009.

[13] H. Hüneke, F. J. Hernández-Molina, F. J. Rodríguez-Tovar et al., "Diagnostic criteria using microfacies for calcareous contourites, turbidites and pelagites in the Eocene-Miocene

slope succession, southern Cyprus," *Sedimentology*, vol. 68, no. 2, pp. 557–592, 2021.
[14] J. Song, Z. Xiaomin, and Z. Dakang, "Application of variogram to automatic identification of sedimentary microfacies," *Acta Petrolei Sinica*, vol. 27, no. 3, p. 57, 2006.
[15] Y. F. Wang, G. Y. Zhai, Y. C. Lu et al., "Sedimentary lithofacies characteristics and sweet-spot interval characterization of the sinian doushantuo formation in upper Yangtze platform, south China," *China Geology*, vol. 2, no. 3, pp. 259–273, 2019.
[16] S. Xuanlong, H. Jinxiang, R. F. Sachsenhofer, and S. H. I. Tiaotiao, "Sedimentary micro-facies and macro heterogeneity of reservoir beds in the third member of the qingshankou formation, Qian'an area, Songliao basin," *Acta Geologica Sinica*, vol. 81, no. 6, pp. 1033–1040, 2007.
[17] A. Ghabeishavi, H. Vaziri-Moghaddam, A. Taheri, and F. Taati, "Microfacies and depositional environment of the Cenomanian of the Bangestan anticline, SW Iran," *Journal of Asian Earth Sciences*, vol. 37, no. 3, pp. 275–285, 2010.
[18] Z. K. Hou, H. L. Cheng, S. W. Sun, J. Chen, D. Q. Qi, and Z. B. Liu, "Crack propagation and hydraulic fracturing in different lithologies," *Applied Geophysics*, vol. 16, no. 2, pp. 243–251, 2019.
[19] J. Han, H. Cheng, Y. Shi, L. Wang, Y. Song, and W. Zhnag, "Connectivity analysis and application of fracture cave carbonate reservoir in Tazhong," *Science Technology and Engineering*, vol. 16, no. 5, pp. 147–152, 2016.
[20] H. Cheng, J. Wei, and Z. Cheng, "Study on sedimentary facies and reservoir characteristics of paleogene sandstone in Yingmaili block, Tarim Basin," *Geofluids*, vol. 2022, Article ID 1445395, 14 pages, 2022.
[21] H. Cheng, P. Ma, G. Dong, S. Zhang, J. Wei, and Q. Qin, "Characteristics of carboniferous volcanic reservoirs in Beisantai Oilfield, Junggar Basin," *Mathematical Problems in Engineering*, vol. 2022, Article ID 7800630, 10 pages, 2022.
[22] C. M. Wang, C. L. Wang, C. L. Liu, S. X. Long, S. X. Wu, and J. T. Zhang, "Sedimentary facies, sedimentary model and evolution of Changxing Formation in northeast Sichuan Basin," *Geology in China*, vol. 38, no. 3, pp. 594–609, 2011.
[23] H. Cheng, D. Yang, C. Lu, Q. Qin, and D. Cadasse, "Intelligent oil production stratified water injection technology," *Wireless Communications and Mobile Computing*, vol. 2022, Article ID 3954446, 7 pages, 2022.