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Sedimentary Characteristics and Models of Restricted Braided River Deltas Under the Control of Paleogeomorphology: A Case Study of the Jingjingzigou Formation in the Ji 451 Well Area, Jimusar Sag

Ruixin Zhang, Xiaodong Zhao

School of Petroleum, China University of Petroleum (Beijing) at Karamay, 834000, China

ABSTRACT

In order to clarify the sedimentary characteristics of restricted braided river deltas under the control of paleogeomorphology in the Jingjingzigou Formation of the Ji 451 well area in the Jimusar Sag, establish sedimentary models, and understand the distribution patterns of sedimentary sand bodies. A variety of methods, including paleogeomorphologic restoration, logging facies description, lithofacies and sedimentary facies classification, were comprehensively employed to conduct the research. The research indicates that (1) The study area features a paleogeomorphic pattern of "southern bulge and northern depression," with the Jinan uplift developing in the south and a paleolake in the north, separated by a slope formed by the movement of the two fault blocks of the Jinan Fault in the middle. (2) In the second member of the Jingjingzigou Formation in the study area, channel deposits are predominantly developed. Based on lithological characteristics and single-well sedimentary facies analysis, they can be classified into underwater distributary channel and inter-distributary bay microfacies. The underwater distributary channels are distributed in large sets, with interbedded deposits of inter-distributary bays and underwater distributary channels. (3) After being denuded, the clastic materials from the Jinan uplift were transported northward along the slope to the lake basin. With a slope developed in the northern part of the lake basin, the sediments carved out multiple braided channels there. During the transportation process, as the northern shore of the lake basin features a sloped terrain, the sediments are unable to overcome their own gravitational force to continue being transported forward. Ultimately, they accumulate within the lake basin, forming sedimentary bodies that are spatially restricted by the lake basin, with a limited distribution range. These sedimentary bodies differ from the braided river deltas in the traditional sense. In the study area, it is manifested by relatively steep slopes both onshore and underwater, with the lake shore being in close proximity to the foothills. The river channels are short, and they develop only up to the braided river stage before entering the lake water restricted by the local deep-depression paleotopography, forming sedimentary bodies. This sedimentary body features thick sand bodies that rapidly thin out and pinch out in the direction away from the provenance. The sediment sorting and rounding are relatively poor, yet it can serve as a reservoir. The research findings provide a basis for oil and gas exploration in the Ji 451 well area, while also enriching the sedimentary theory of braided river deltas.

KEYWORDS

Jimusar Sag; Jingjingzigou Formation; Sedimentary Characteristics; Sedimentary Model; Braided River Delta.

1. INTRODUCTION

As a focal point in the field of sedimentology research, restricted sedimentary bodies refer to special sedimentary units whose depositional space and distribution range are constrained by factors such as paleogeomorphology, tectonic activity, or sedimentary environment. They are widely developed in tectonic settings such as continental rift basins and passive continental margins, exhibiting unique sedimentary characteristics and distribution patterns, and holding significant implications for oil and gas resource exploration. Based on differences in sedimentary environments, restricted sedimentary bodies can be classified into restricted deltas, restricted channels, and restricted sublacustrine fans[1, 3].Among them, the delta formed by the joint constraints of paleovalleys and fault uplifts is defined as a restricted delta[2]. It exhibits a long, strip-like arrangement in plan view and has a relatively large length-to-width ratio[4]. Based on the degree of restriction, they can be further classified into three categories: restricted, semi-restricted, and unrestricted sedimentary systems. Restricted sedimentary systems primarily develop in lake basins and are influenced by the uplift of surrounding topography. Semi-restricted sedimentary systems arise from sedimentation triggered by frontal or lateral barriers, while unrestricted sedimentary systems are not influenced by accommodation space constraints, with their depositional extent determined by sediment supply conditions[5]. Among them, restricted sedimentary bodies generally exhibit characteristics such as narrow depositional space, concentrated sediment supply, significant stratigraphic thickness, and poor particle sorting. For instance, the fan delta of the Xiazijie Formation in the Mahu Depression is constrained by the lake basin topography formed through tectonic activity. The provenance area is predominantly composed of conglomerates, with sediment composition consistent with that of the source region, featuring high matrix content and primarily developing channel deposits[6].The fan-delta sedimentary bodies of the Lower Cretaceous Way Group in northern Chile are constrained by half-graben tectonics, with granular flows playing a dominant role in the sedimentary process[7].Therefore, the development of restricted sedimentary bodies is primarily controlled by tectonic activity, paleogeomorphology, and sediment supply[6].Within such sedimentary bodies, paleogeomorphic elements such as paleovalleys, fault uplifts, and slope breaks form "restricted conduits" for sediment transport, governing the distribution orientation of the sedimentary deposits[3].The rate and type of sediment supply influence the grain size and sand content of sedimentary bodies, thereby leading to the formation of different types of restricted sedimentary bodies.

Early exploration in the Jimusar Depression revealed the discovery of sandy conglomerate oil reservoirs in the Wutonggou Formation and shale oil in the Lucaogou Formation[8.9]. In recent years, with the gradual intensification of exploration efforts, multiple high-risk exploration wells have been deployed, leading to significant breakthroughs in oil and gas exploration. In 2020, Well Jixin 2 of the Tuha Oilfield achieved industrial oil flow in the Jingjingzigou Formation. In December 2023, Well Ji 451 once again achieved industrial oil flow in the Jingjingzigou Formation, and this breakthrough in oil and gas exploration demonstrates the exploration and development potential of the Permian Jingjingzigou Formation. Through a review of previous literature, it was found that studies on the sedimentary characteristics of the Jingjingzigou Formation have primarily focused on multiple outcrop sections along the southern and southeastern margins of the Junggar Basin[10.11]. These studies suggest that the formation predominantly features traditionally defined unrestricted braided river delta sedimentary facies. Research on the Jingjingzigou Formation in the Jimusar Depression has primarily focused on understanding reservoir characteristics, geochemical features, and hydrocarbon accumulation models[12]. Therefore, this study conducts an in-depth analysis of the sedimentary setting, lithofacies types, and planar distribution characteristics of the Jingjingzigou Formation by utilizing core and well-logging data from the newly drilled Well Ji 451, combined with limited coring data from earlier wells. The study clarifies how paleogeomorphology influences the sedimentary facies and sandbody distribution patterns of the Jingjingzigou Formation in the Ji 451 well area, defines a braided river delta sedimentary system set against a backdrop of restricted ancient depressions, establishes a corresponding sedimentary model, and thereby enriches the theoretical framework of braided river delta sedimentation.

2. REGIONAL GEOLOGICAL OVERVIEW

The Junggar Basin was in a transition phase from rift to depression during the Permian, characterized by a continental sedimentary environment[13]. During the Late Hercynian period, the ancient Xi and Shaqi uplifts were uplifted, and the dustpan-shaped depression began to take shape[14]. During the Indosinian period, the ancient Xi uplift in the eastern part of the depression experienced slow uplift, leading to further development of the depression. In the early Yanshanian period, the uplifts in the northern and western parts of the depression underwent uplift and erosion. In the mid-Yanshanian period, intense uplift occurred in the northern, southern, and western regions of the depression, while the ancient Xi uplift remained structurally stable. In the late Yanshanian period, intense tilting and erosion took place in the eastern, western, and southern parts of the depression, marking a critical phase for the final shaping of the depression[15]. During the Himalayan period, the Fukang fault zone in the southern part of the depression underwent intense compressional uplift, while uplift in the eastern and northern regions was less pronounced. The Beisantai uplift in the western part maintained stable sedimentation, ultimately shaping the present-day basic structural framework of the depression[16]. The formation of the Jimusar Depression resulted from the superimposition of multiple tectonic movements spanning from the Late Hercynian to the Himalayan periods, exhibiting an overall dustpan-shaped structural characteristic with "faulting in the north, west, and south, and overlap in the east"[17].

The Jimusar Depression is a dustpan-shaped depression controlled by faults on three sides, with a relatively stable structure characterized by lower elevations in the west and higher elevations in the east within the depression area. Multiple low-amplitude nose-like uplifts controlled by faults are developed here. The stratigraphic sequence from bottom to top includes Carboniferous, Permian, Triassic, Jurassic, Cretaceous, Paleogene, Neogene, and Quaternary formations[15]. During the Permian sedimentary period, lacustrine facies dominated, undergoing a complete lake transgression-regression cycle. The paleoclimate shifted from arid and hot to warm and humid, leading to the desalination of lake waters. The overall sediment composition was predominantly fine-grained[16]. From top to bottom, the Upper Permian Wutonggou Formation, Middle Permian Jingjingzigou Formation, and Lucaogou Formation were developed, with the Lower Permian absent [10] (Figure 1). Controlled by NE-SW trending and near NS trending faults, the Jingjingzigou Formation develops three major low-amplitude nose-uplift zones from west to east: the Jixin 1, Shuangji, and Jidong zones. The Jidong fault-controlled nose-uplift belt features four significant low-amplitude nose-shaped uplifts that extend into the hydrocarbon-generating depression. The Jingjingzigou Formation, situated beneath the high-quality lacustrine source rock layer of the Lucaogou Formation, is overlain by the Lucaogou Formation and underlain by the Wulabo Formation, with both showing conformable contacts. This formation comprises two distinct lithological strata, which can be divided into the lower Jing 1 Member and the upper Jing 2 Member from bottom to top. The lithology of Jing 1 Member (P2jj1) is characterized by brown, thick-bedded mudstones interbedded with thin layers of silty fine sandstone and argillaceous siltstone. The sand bodies in the lower part are 15-30 m thick, exhibit poor continuity, and are developed only locally. The Jing 2 Member (P2jj2) is predominantly composed of gray to dark gray sandstones interbedded with thin mudstones. The upper sand bodies are approximately 50 meters thick, with excellent continuity, making them high-quality reservoirs. The study area is located in the Ji-451 well block, bordered by the Jinan uplift to the south and separated from it by the Jinan fault zone, with the Jimusar Depression situated to the north. This has resulted in a topographic pattern of "uplift in the south and depression in the north." The provenance from the Jinan uplift in the south undergoes erosion and is transported northward, leading to the accumulation of substantial sediment deposits in the northern lake basin.

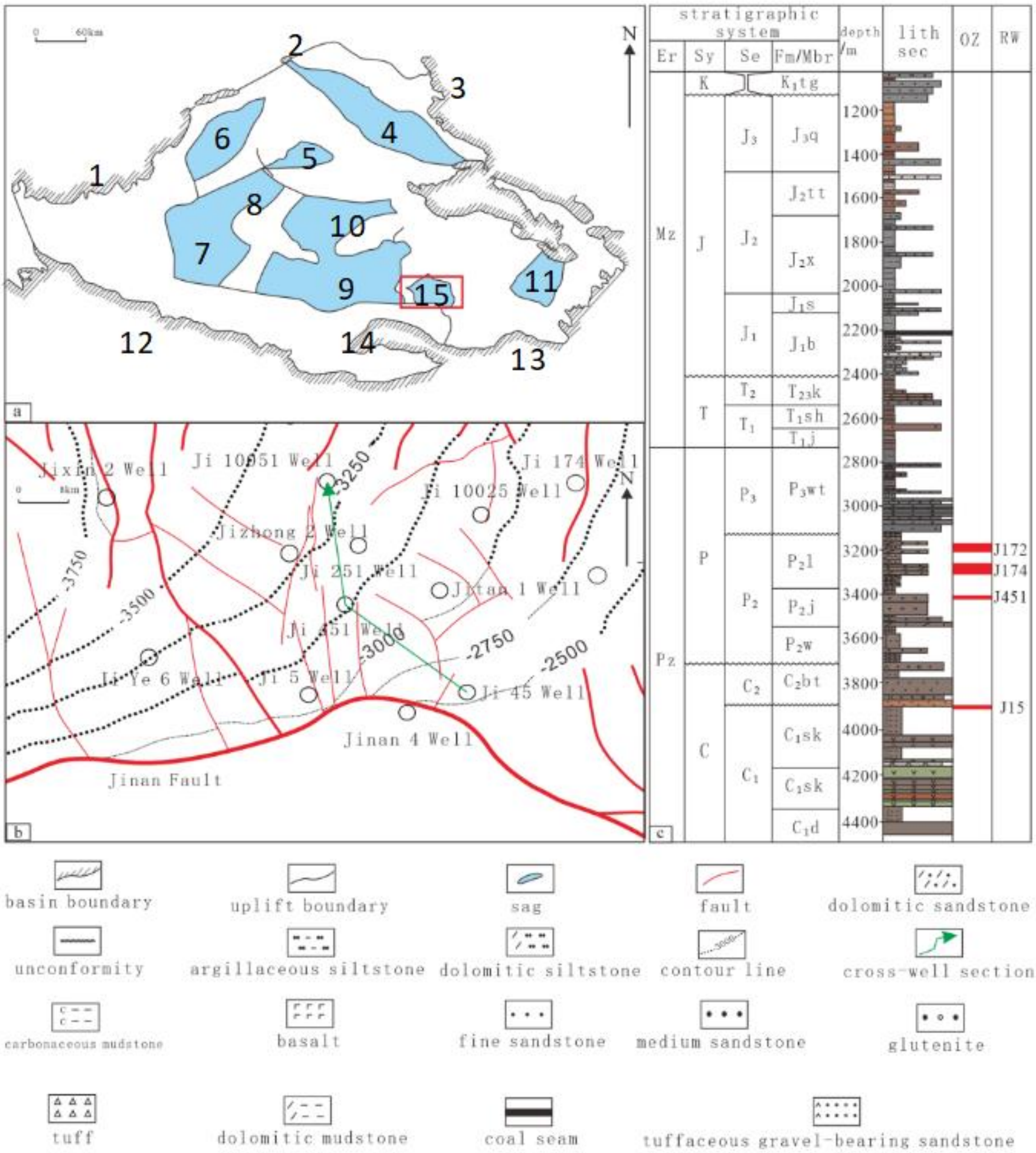

Fig. 1 Geographical location of the Jimusar Depression, research scope of the JI-451 well area, comprehensive columnar chart

Geographic location map of Jimusar; b. Scope map of Well Ji-451 area; c. Comprehensive stratigraphic column of Well Ji-451 area

Numbering of Figure a:1. Zhayier Mountains 2. Delun Mountain 3. Qinggelidi Mountains

4.Suosuoquan Sag 5. Yingxi Sag 6. Mahu Sag 7. Shawan Sag 8. West Pen-1 Well Sag 9. Fukang Sag 10. Dongdaohaizi Sag 11. Guqiantan Sag 12. Yilin Heibiergen Mountains 13. Bogda Mountains 14. Fukang Fault Zone 15. Jimsar Sag

3. ANCIENT GEOMORPHIC CHARACTERISTICS

By studying ancient geomorphic features, the types and distributions of sedimentary facies can be clearly identified, thereby enabling the determination of source-reservoir-seal assemblages for hydrocarbon reservoirs[17.19]. The stratigraphic residual thickness method and amplitude attributes were employed to investigate the paleogeomorphology and sandbody distribution during the sedimentation of the Jingjingzigou Formation in the Ji-451 well area of the study region. The residual thickness method utilizes the remaining thickness from the erosion surface to its underlying horizontal datum plane to approximately reconstruct the paleogeomorphology. A greater residual thickness indicates a higher paleotopography[20], while amplitude attributes are utilized to determine lithological distribution ranges based on variations in amplitude and energy of positive and negative phases[21].

The Ji-451 well area preserves the Jinan uplift and local paleolake basins formed by intense compressional uplift along the Fukang fault zone during the Himalayan orogeny[16]. The Jinan uplift served as a provenance zone, while the movement of the two fault blocks along the Jinan fault zone formed a steep slope. The lake basin acted as accommodation space, enabling sediment derived from the uplift to be transported into the basin via the steep slope. As shown in the residual thickness map (Figure 2a), the sedimentary area is relatively small with significant thickness, indicating limited accommodation space in the lake basin that restricted large-scale sediment dispersal. During the second member of the Jingjingzigou Formation, substantial sand bodies accumulated in the lake basin. Controlled by the paleolake basin topography and sediment supply, these sand bodies rapidly thinned and pinched out along the basin margins distal to the provenance, exhibiting limited lateral extent. The sand bodies, which are relatively concentrated in distribution, serve as favorable hydrocarbon reservoirs (Figure 2b). Through tracking and correlation of seismic reflection events (seismic horizons) and analysis of their termination relationships on seismic profiles, it was observed that the lower member of the Jingjingzigou Formation (Jing-2 Member) is overlain by the Lucaogou Formation with downlap and pinch-out features. This indicates a progressively deepening depositional environment during that period. The sediments exhibit a progradational feature advancing toward the center of the lake basin. The lower part of the first member of the Jingjingzigou Formation (Jing-1 Member) is truncated, forming an angular unconformity with a dipping contact. This indicates uplift and subsequent weathering-erosion of the strata during this period, leading to the formation of a paleolake basin (Figure 2c).

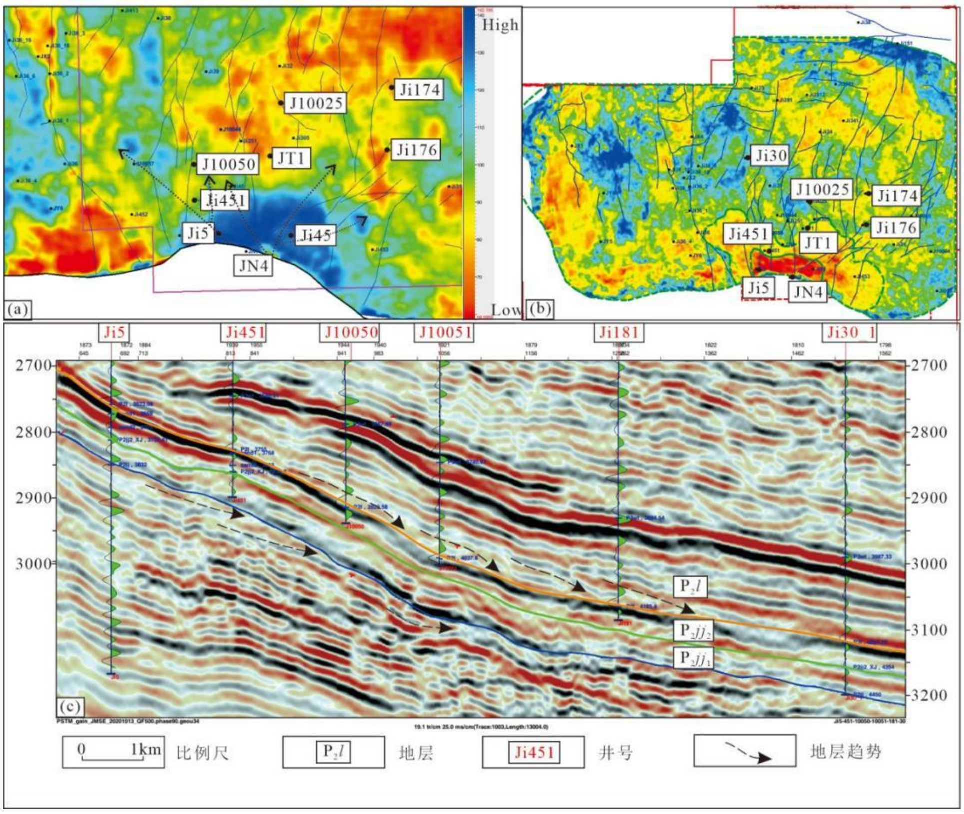

Fig 2 Ji 451 Well Area Ancient Landforms and Seismic Map

a. Residual thickness map of the Permian Jingjingzigou Formation in Well Ji-451 area; b. Sand body amplitude attribute map of the second member of the Permian Jingjingzigou Formation in Well Ji-451 area; c. Seismic profile interpretation of Well Ji-451 area

4. SEDIMENTARY CHARACTERISTICS

4.1. Lithological characteristics

The rock types in the second member of the Jingjingzigou Formation in the Well Ji-451 area are predominantly feldspathic lithic sandstones and lithic sandstones (Figure 3e). The lithologies include (calcareous-bearing) fine-grained feldspathic lithic sandstones (Figure 3a), medium-fine-grained feldspathic lithic sandstones (Figures 3b and 3c), and medium-coarse-grained to fine-grained feldspathic lithic sandstones (Figure 3d). The sorting is moderately poor, with sub-angular to angular grain rounding, low maturity, and relatively short transportation distance. The clastic grains are predominantly feldspar, while quartz content is extremely low, indicating poor stability. The interstitial materials predominantly consist of iron-bearing calcite, micritic calcite, and chlorite, with minor amounts of muddy matrix, authigenic albite, pyrite, and iron-bearing dolomite (Figure 3a-d). Chlorite matrix is evenly distributed along grain margins, while micritic calcite and calcite are uniformly dispersed among the grains, with pyrite cements sporadically distributed. The phenomenon of calcite replacing clastic grains (such as calcite replacement) is observed (Figure 3b).

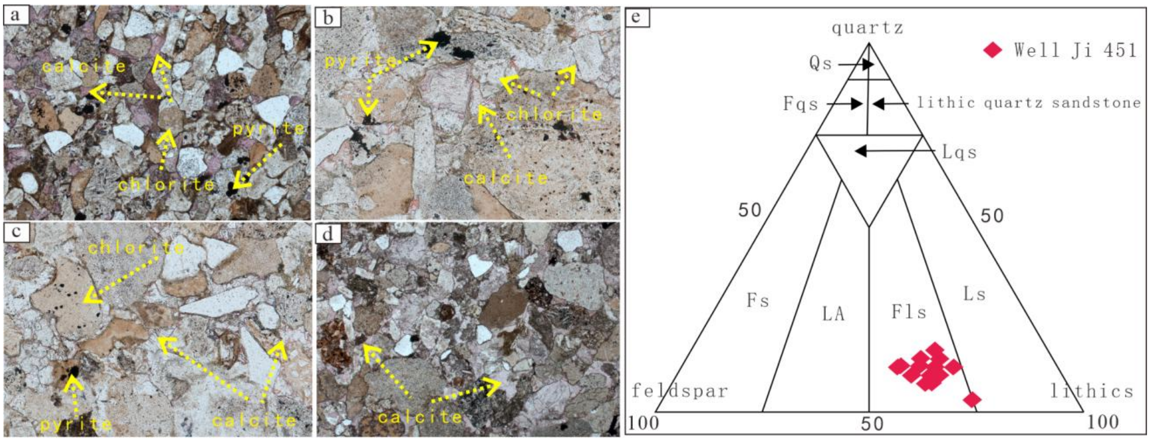

Fig 3: Thin sections and lithological triangular diagram of the Jingjingzigou Formation in Well Ji-451 area

(a)3768.10 fine-grained feldspathic lithic sandstone at 5X; (b) 3772.06 medium-fine-grained feldspathic lithic sandstone at 5X; (c) 3778.05 medium-fine-grained feldspathic lithic sandstone at 2.5X; (d) 3826.75 medium-coarse-grained feldspathic lithic sandstone at 5X; (e) lithological triangular diagram.

4.2. Grain Size Characteristics

Based on grain size analyses conducted at various depths within the study area (Figure 4a, b), it is found that the Jingjingzigou Formation in the study area exhibits a "two-segment" grain size distribution pattern, characteristic of typical fluvial channel deposits, with predominant saltation and suspension components, while the traction (rolling) component is poorly developed. Among them, the suspension component accounts for approximately 20-30%, while the saltation component makes up about 70-80%, with saltation being the dominant mode of transportation. The slope of the saltation component is around 60°, indicating good sorting, whereas the slope of the suspension component is 30°, reflecting poor sorting. The intersection point φ value between the saltation and suspension components ranges from 3 to 4, with an inflection point at 60-70%, reflecting strong and stable hydrodynamic conditions during deposition.

In the study area, rock grain sizes predominantly concentrate above 1.58 mm, primarily consisting of sandstone and conglomerate with relatively coarse particles. The saltation component dominates, while the suspension component, with grain sizes below 0.6 mm, mainly comprises medium- to fine-grained sandy mudstone and is transported via suspension. Overall, the intermingling of particles of varying sizes exhibits characteristics typical of fluvial traction currents in river channels.

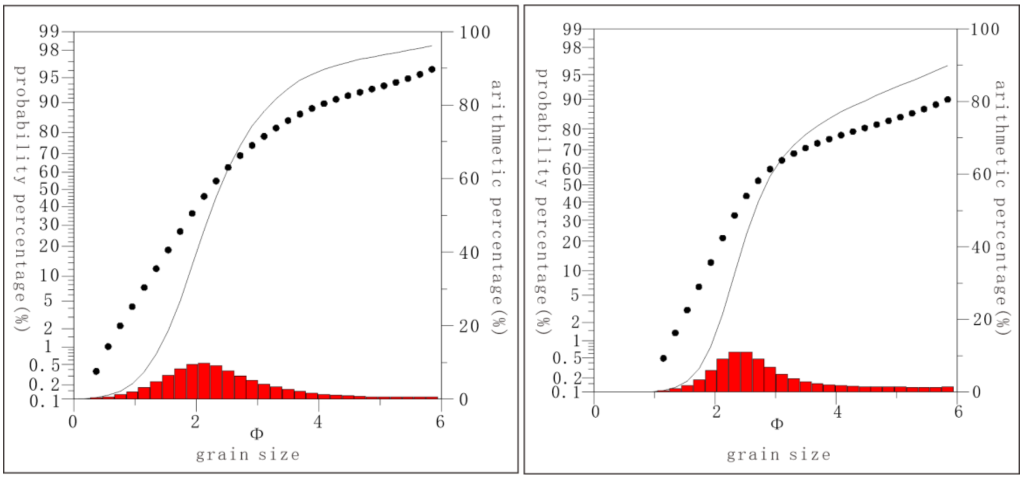

Fig 4. Grain Size Accumulative Curve Diagram of the Jingjingzigou Formation in the Ji-451 Well Area

(a)Sample at 3772.37 m, Sample No.: J41; (b) Sample at 3825.7 m, Sample No.: J45.

4.3. Sedimentary Structures and Colors

Five main types of sedimentary structures are developed in the study area. (1) Massive structure: It is characterized by the absence of distinct fine-layer divisions, with a homogeneous or non-directional internal texture. This indicates that the sandy particles were primarily deposited through sudden and rapid accumulation, formed by the strong hydrodynamic scouring of channels in the braided river delta front (Figure 5a). (2) Directional alignment structure: Gravels can be observed to be arranged along a certain direction, which is consistent with the unidirectional flow characteristics of channel deposits (Figure 5b). (3) Scour surface: Primarily composed of sandy conglomerate, with pronounced scouring at the river bottom, representing a typical characteristic of channel deposits in braided river deltas (Figure 5d). (4) Small-scale cross-bedding: Formed at the edges of river channels where the flow velocity decreases and the flow direction becomes unstable, resulting in erosion on both sides of the channel. This feature marks lateral channel migration or flood overflow (Figure 5e). (5) Parallel bedding: In the middle of the river channel, the water flow exhibits high and stable velocity with a consistent flow direction, primarily characterized by transportation processes (Figure 5c, f).

Through core observation, it was found that gray sandstone and dark muddy gravel are developed in the study area, indicating a weakly oxidizing - weakly reducing sedimentary environment. This suggests that the study area is located in relatively shallow underwater positions. Combining previous research findings with the regional sedimentary background, it can be concluded that the study area developed a braided river delta front sedimentary subfacies.

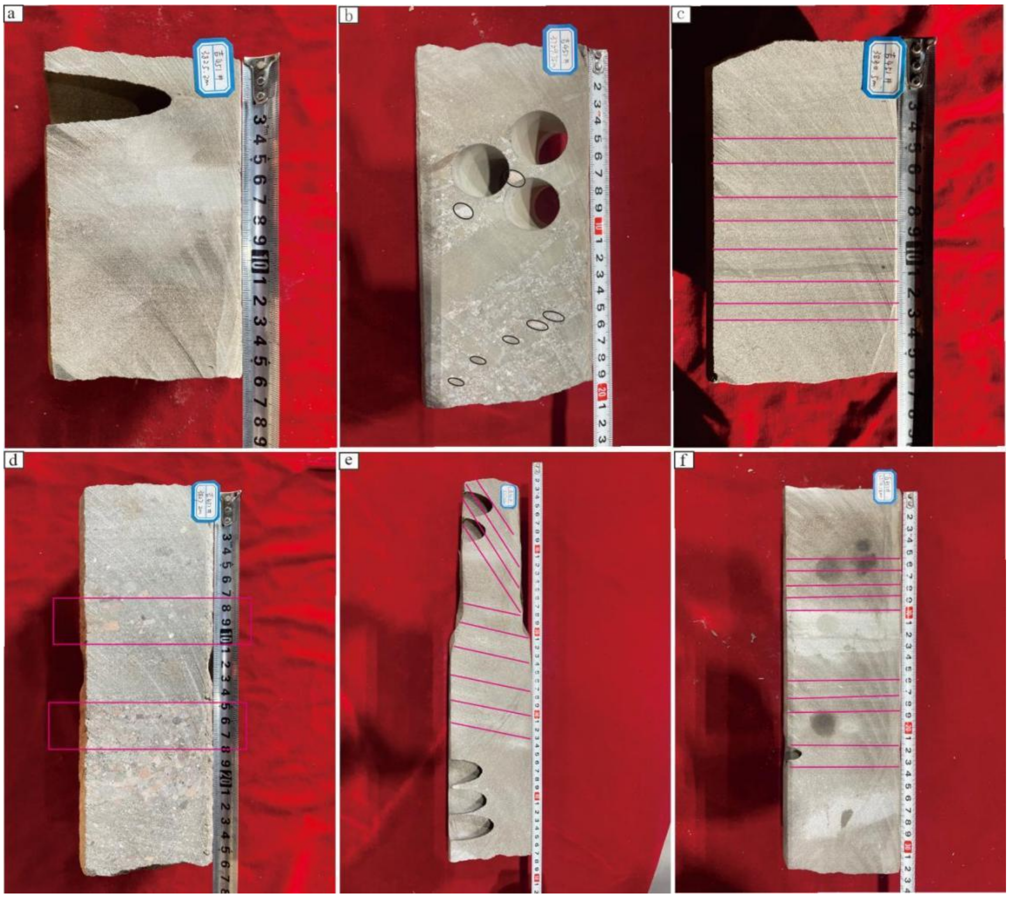

Fig 5 Core photographs of Well Ji-451

(a)3825.2 Massive sandstone; (b) 3769.75 Gravel with directional alignment; (c) 3830.5 Sandstone with parallel bedding; (d) 3827.2 Sandy conglomerate with scour surface; (e) Sandstone with small-scale cross-bedding; (f) Sandstone with parallel bedding

4.4. Sedimentary Facies Characteristics of Single Wells

In the second member of the Jingjingzigou Formation in the study area, the main developed microfacies are underwater distributary channels and interdistributary bays. The well section from 3822 to 3834 m is predominantly characterized by the underwater distributary channel microfacies, with the natural gamma-ray curve exhibiting typical low-value box-shaped characteristics. This reflects the characteristics of pure sandstone with extremely low shale content. The overall high resistivity curve in this well section indicates that the sandstone is dense, representing sedimentary products from river channels with stable and strong hydrodynamic conditions (Figure 5a). The well section from 3800 to 3822 m is characterized by interbedded sandstone and mudstone deposits, corresponding to the alternating development of underwater distributary channels and interdistributary bays. The interdistributary bays are predominantly composed of mudstone, with the natural gamma-ray curve displaying a regular vertical distribution of alternating high and low values, clearly indicating periodic fluctuations in hydrodynamic conditions (Figure 5b).

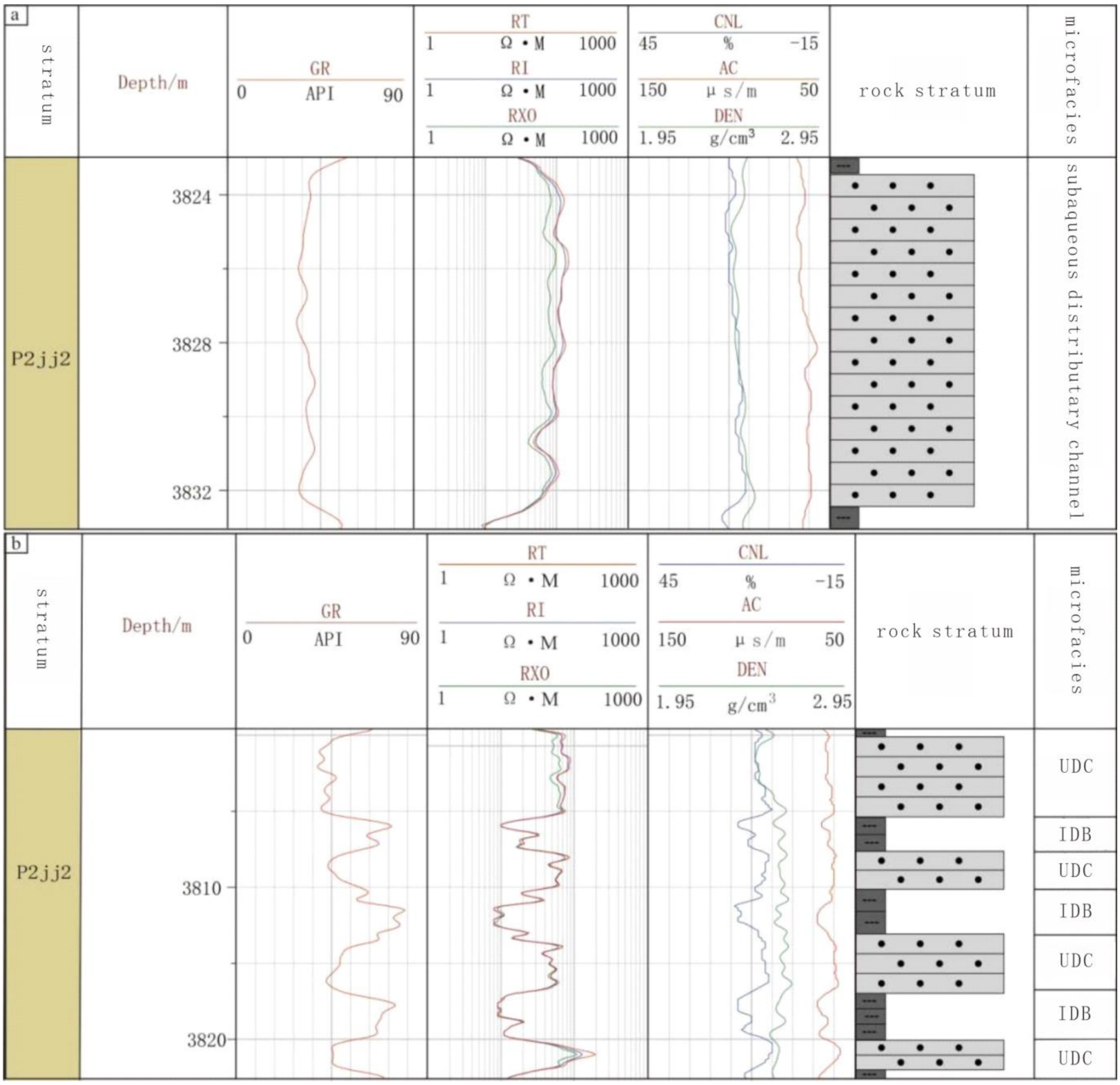

Fig 6 Single-well Sedimentary Microfacies Diagram of the Jingjingzigou Formation in Well Ji-451

4.5. Characteristics of Connected-Well Sedimentary Facies

Based on single-well facies analysis, the connected-well correlation method is employed to comprehensively determine the scale of sedimentary facies and analyze their evolutionary processes and lateral variation patterns. Sedimentary facies analysis was conducted across Well Ji-5, Well Ji-451, and Well Ji-10051 (as shown in Figure 1b and Figure 6). The connected-well profile commences at the boundary between the Jinan uplift and the ancient lake basin, terminating at the northern margin of the lake basin. It vividly illustrates the sedimentary environmental transition from a shore-shallow lake in a semi-arid setting to a braided river delta in an arid environment. This process is governed by multiple factors, including the paleotopographic configuration, sediment supply patterns, and hydrodynamic conditions. During the depositional period of the first member of the formation, shore-shallow lake facies sedimentary bodies were widely distributed along the connected-well profile, with lithology primarily consisting of fine-grained mudstone and siltstone. The weak hydrodynamic conditions and limited sediment supply reflect a relatively stable shallow-water environment under semi-arid conditions. During the depositional period of the second member of the Jingjing Formation, braided river delta sedimentary facies developed, characterized by a continuous increase in thickness and a gradual expansion in lateral extent. The coarse-grained content in the rocks significantly increased, indicating enhanced fluvial erosion and transport capacity, as well as sufficient sediment supply, under arid conditions. This reflects sedimentary characteristics of a transition from weak to strong hydrodynamic conditions. Due to the steep paleotopographic gradient in the study area, sand bodies rapidly accumulated. Additionally, the small lake basin area combined with its considerable depth resulted in limited sediment supply. Consequently, sand bodies exhibited significant depositional thickness near the source side, while rapidly thinning in regions farther from the source due to their proximity to the opposite shore, ultimately accumulating within the lake basin. These characteristics reflect the paleotopographic features of the study area, namely a "locally deep-depressed lake basin with lake shores in close proximity to sediment sources, short river courses, steep slopes, and regions distant from sources but adjacent to lake shores." This indicates a rapid unloading process of clastic materials transported from the source areas, with sand bodies accumulating proximally and developing sand-rich sedimentary bodies dominated by channel deposits.

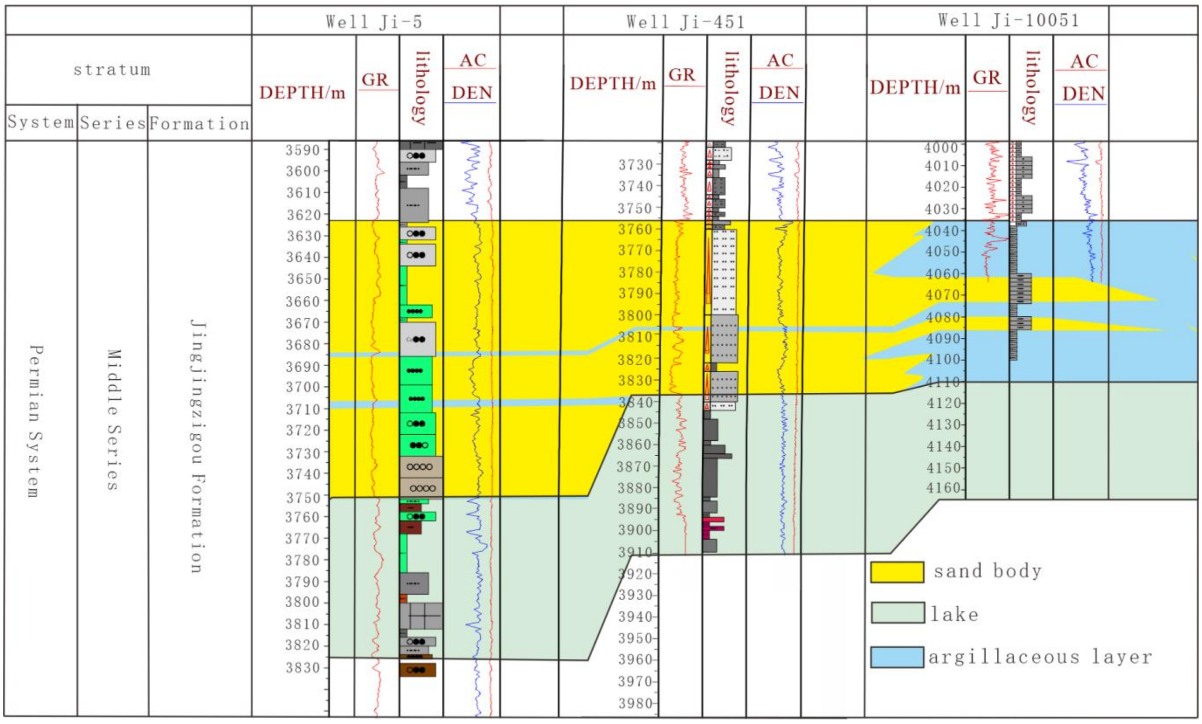

Fig. 7 Ji Mu Sa'er Depression Jingzigou Formation Sandbody Well-to-Well Correlation Diagram

4.6. Characteristics of Planar Facies

The planar facies distribution of the Jingjingzigou Formation was determined based on single-well sedimentary facies, connected-well sedimentary facies, lithofacies, and residual thickness of paleogeomorphology (as shown in Figure 7).The study suggests that during the sedimentary period of the Jingjingzigou Formation in the Jimusaer Depression, due to the influence of paleoslope topography and external factors, sediment sources were eroded and transported into the lake basin under the action of their own gravity. Due to the steep slope over which sediment sources were transported, as the distance from the source increased and approached the center of the lake, the slope rapidly flattened, leading to a swift reduction in hydrodynamic energy. Consequently, clastic materials began to deposit. The filling effect of these sediments reduced the available accommodation space, causing the lake area to shrink. Additionally, the erosive action of clastic materials during transportation contributed to the formation of a braided river delta with multiple distributary channels. This type of sedimentary body exhibits proximal source characteristics, having not undergone long-distance mechanical sorting. As a result, its sorting and rounding are relatively poor, with multiple branching channels developed. In such a proximal sedimentary system, sand bodies are relatively concentrated in distribution and exhibit significant thickness, enabling the formation of large-scale effective reservoirs.

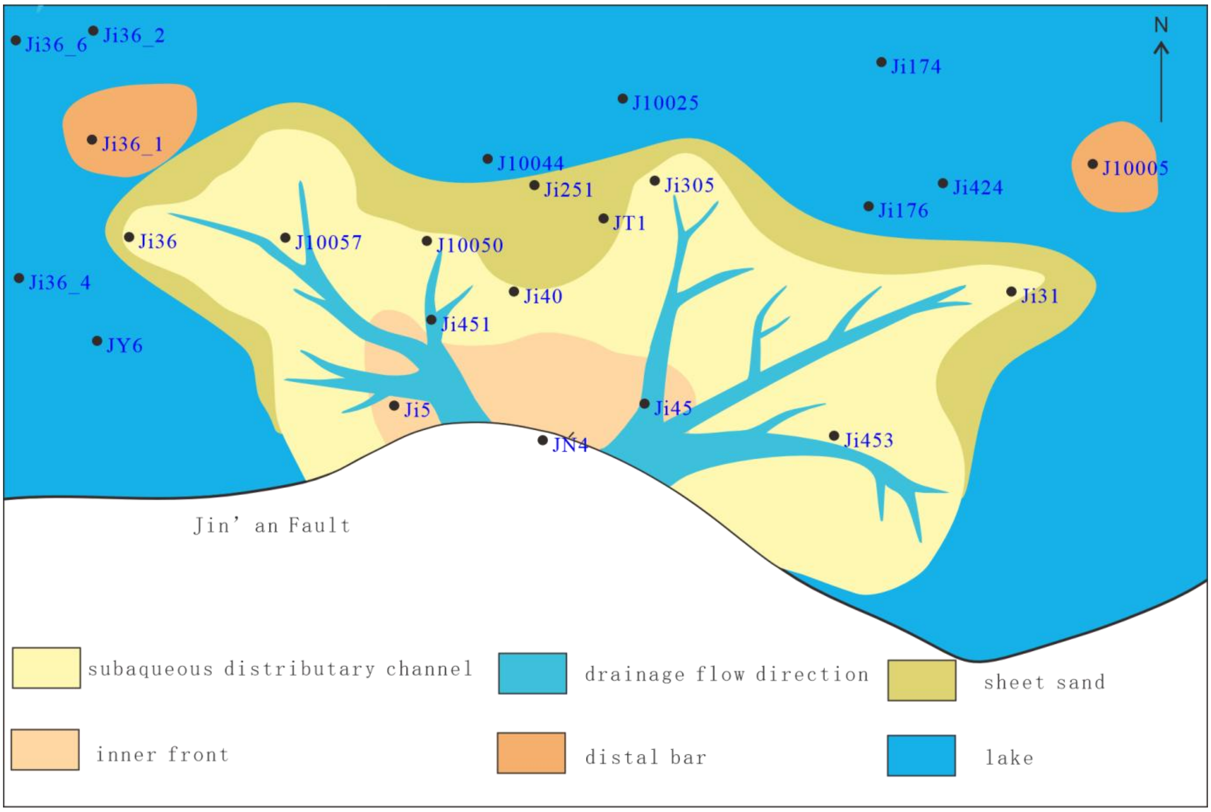

Fig. 8 Plan View of Well 451 Area, Jingzigou Formation, Jimusar Sag

5. SEDIMENTARY FACIES MODEL

Through a comprehensive analysis of connected-well sedimentary facies and planar facies distribution in the study area, a sedimentary model was established (Figure 8). During the lake regression period in the Permian Jingjingzigou Formation of the Ji 451 well area, the available accommodation space continuously decreased, compelling the deltaic sedimentary bodies in the Ji 451 well area to rapidly advance towards the center of the lake basin, exhibiting typical progradational sedimentary characteristics. The Ji 451 well area served as the regional subsidence center, characterized by the greatest water depth and a relatively steep slope. Under such conditions, sand bodies remained in an unstable state over extended periods, with sedimentary interfaces prone to tilting and deformation. When subjected to external triggering factors such as tectonic activity or abrupt changes in hydrodynamic conditions, the massive sand bodies at the front of the braided river delta would fracture and slide, transporting along the slope into the lake basin and carving out multiple braided channels. In the northern part of the lake basin, a slope terrain is also developed. Here, sand bodies are unable to overcome their own gravity for further long-distance transportation and ultimately accumulate within the ancient lake basin, forming a set of sedimentary bodies constrained by the ancient lake basin's topography. These sedimentary bodies exhibit a triangular shape in plan view, with multiple braided channels developed, representing a braided river delta sedimentary facies. Unlike traditional braided river deltas, this type of sedimentary facies is constrained by paleotopography, featuring steep slopes both onshore and offshore. The lake shore is situated close to the foothills, with short river courses that, upon reaching the braided river stage, enter lake waters restricted by local deep depressions in the ancient topography, forming deltaic sedimentary bodies. These deposits are the result of rapid clastic material transportation and unloading under the influence of strong hydrodynamic forces and topographical constraints, exhibiting petrological characteristics of grain-supported textures and moderate to poor sorting. As seen in the model cross-section diagram, wells Ji 5 and Ji 451 exhibit extremely thick sand bodies, while at well Ji 10051, which is far from the source area, the sand bodies rapidly thin out and pinch out, demonstrating sedimentary characteristics of "thick sand bodies at the root and rapid thinning of sand bodies in the direction away from the source" (Figure 8).

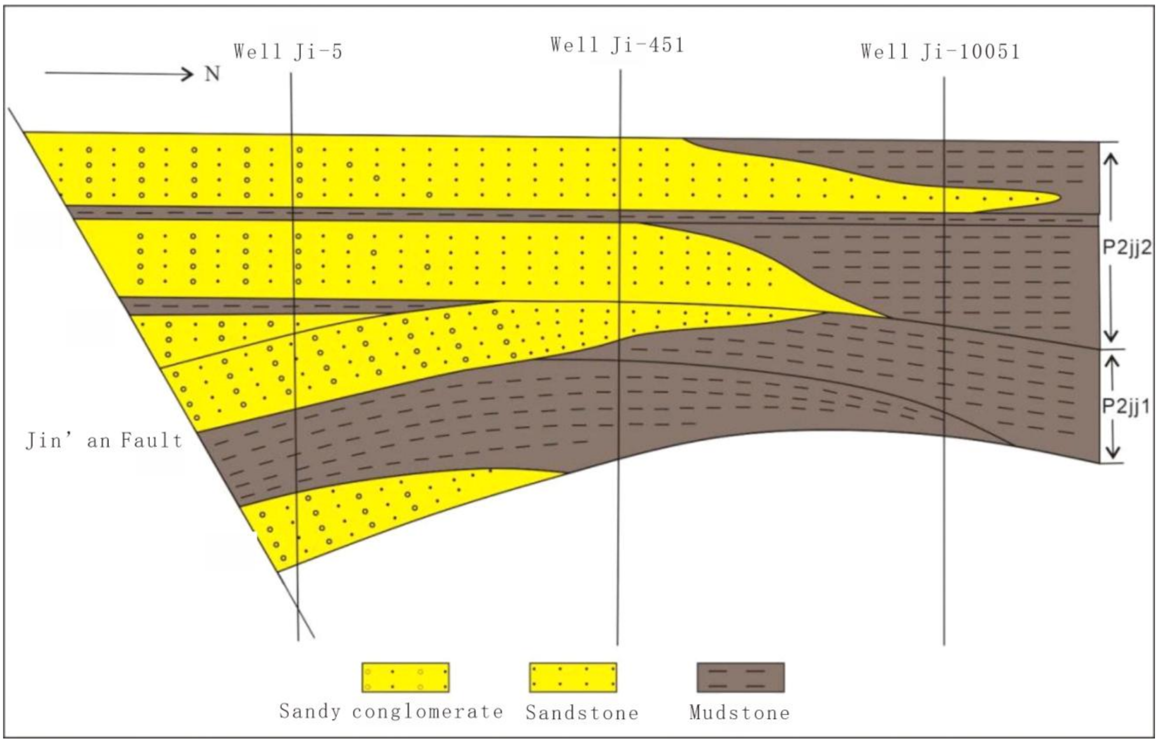

Fig. 9 Sedimentary Facies Profile of Jingzizi Formation in Well 451 Area, Southern Ji

6. CONCLUSION

(1)The rock types in the second member of the Jingjingzigou Formation in the Ji 451 well area are predominantly feldspathic lithic sandstones and lithic sandstones. The lithology includes (lime-bearing) fine-grained feldspathic lithic sandstones, medium-fine-grained feldspathic lithic sandstones, and medium-coarse to fine-grained feldspathic lithic sandstones. The sorting is moderate to poor, with sub-angular to angular rounding, indicating low maturity and relatively short transport distances. Five types of sedimentary structures are developed: massive, directionally arranged structures, scour surfaces, small-scale cross-bedding, and parallel bedding, which are typical of channel deposits. Two primary microfacies and their interbedded deposits are predominantly developed: underwater distributary channels and interdistributary bays. The underwater distributary channels are mainly composed of pure and dense sandstones, indicating stable and strong hydrodynamic conditions. In contrast, the interdistributary bays are primarily mudstone-dominated and exhibit interbedding with the underwater distributary channels.

(2) The Permian Jingjingzigou Formation in the study area exhibits a topographic pattern characterized by a "southern uplift and northern depression." The southern region features the Ji'nan Uplift, which serves as the provenance area, while the northern region is a depression in the ancient lake basin with substantial accommodation space for sediment accumulation. These two areas are separated by the Ji'nan Fault, and the movement of its two fault blocks has created a slope. The clastic materials from the Ji'nan Uplift undergo erosion and are transported along the slope, carving out multiple braided channels. During the transportation process, due to the presence of a slope in the northern part of the lake, the sediments are unable to overcome their own gravity for further transportation and ultimately accumulate in the ancient lake basin. This results in the formation of

sedimentary bodies characterized by thick sand bodies near the source area and a rapid thinning of sand bodies away from the source. In plan view, these deposits exhibit a triangular shape and are distributed within a restricted braided river delta, whose extent is controlled by the topography of the ancient lake basin. This depositional system is characterized by relatively steep slopes both onshore and offshore, with the lake shore situated close to the foothills, resulting in short river courses. The rivers only develop to the braided river stage before entering the sedimentary bodies within the lake basin, which are restricted by local deep depressions in the ancient topography. The sandstone bodies within this depositional system are extensively distributed and can serve as excellent reservoirs.

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