

Article

Architectural Characteristics and Distribution Patterns of Gravity Flow Channels in Faulted Lake Basins: A Case Study of the Shahejie Formation in the Banqiao Oilfield, China

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Abstract: Internal depositional architecture and sand body distribution are the main challenges faced in the development of gravity flow channel deposits in China. Despite significant progress in the exploration and development of gravity flow deposits in recent years, our understanding of the internal architecture of composite sand bodies within gravity flow channels is still limited. Gravity flow channels represent a widely developed sedimentary type in the Shahejie Formation of the Banqiao Oilfield, Huanghua Depression. The lack of understanding of the spatial stacking relationship of gravity flow channel sand bodies hinders further development and remaining oil recovery within the oilfield. Through this study, we aimed to dissect the composite channels (5th architectural units) and single channels (4th architectural units) at the study area, using a combination of well logs and seismic data. We explored the identification criteria and spatial distribution characteristics of internal architectural elements within gravity flow channel reservoirs, based on abundant drilling data, well density grids, and 3D seismic data. By identifying and delineating single channels, we were able to summarize six identification criteria for single channels, including relative elevation differences, curve shapes, and the number of interbeds. We obtained the sand body scale and aspect ratio of single channels and established three depositional architectural patterns, i.e., isolated, lateral migration, and vertical accretion, thus revealing the differences in the spatial stacking relationships of sand bodies in different structural locations (blocks). This work provides new insights into the depositional architectural patterns of gravity flow channel deposits in the Banqiao Oilfield, Huanghua Depression.

Keywords: braided river deposition; reservoir architecture; three-dimensional architecture modeling



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1. Introduction

For a long time, the marine environment has been the main focus of research on gravity flow deposition [1]. Since Mutti and Normark proposed a classification scheme for marine gravity flow deposition units in 1991, including channel, levee, lobe, channel-lobe transition zone, and erosional features, the establishment of predictive gravity flow deposition models has become crucial for deepening our understanding of gravity flow deposition patterns and effectively guiding exploration for deepwater sedimentary hydrocarbon resources [2,3]. Gravity flow channels are commonly developed in deepwater marine sedimentary systems, and, due to their large scale and good reservoir quality, they have become important targets for scientific research, including for oil and gas exploration and development [4,5]. Normark classified gravity flow channels into erosional, erosional-depositional complex, and depositional types, based on the intensity of erosion or deposition. In addition, Mayall and Wynn divided channels into straight, low-sinuosity, and high-sinuosity types, based on channel curvature, while Moody classified channels into restrictive, low-restrictive, and non-restrictive (lobe) types, based on the degree of channel confinement [6–8]. The classification

of these different types of marine gravity flow channels has deepened our understanding of their depositional processes and patterns, as well as promoted efficient exploration and development of deepwater gravity flow sedimentary hydrocarbon resources.

The study of lacustrine gravity flow deposition has only recently emerged. Zhang Jiaqiang et al. conducted research on the deposition types, distribution characteristics, sand body structures, sedimentary processes, and deposition models of distal gravity flows in order to clarify the controlling factors of sand body structures in lacustrine distal gravity flow deposits [9–11]. Qiqi LYU et al. used paleogeomorphological reconstruction methods to study the characteristics and development patterns of gravity flow deposition, revealing the controlling effect of micro geomorphology on gravity flow deposition [12]. Liu Fen, Zhu Xiaomin, and others conducted systematic research on lacustrine bottom fans and slumps in gravity flow sedimentary systems, combining facies models with gravity flow types to study the compositional characteristics and development patterns of gravity flow sediments in deep lake areas more intuitively [13]. Zhang Xiaohui et al. systematically studied the formation mechanisms and deposition models of sandy debris flows and turbidity currents in gravity flow deposition, based on a summary and analysis of gravity flow deposition theories [14]. With the rapid development of computer technology, the use of machine learning methods for sand body prediction has also gradually emerged [15–17]. However, there is currently a lack of detailed dissection and research on lacustrine gravity flow deposition units, especially lacustrine gravity flow channels.

The aim of this study is to use the rich dynamic and static data conditions, such as the well network, core samples, tracers, analog outcrops, and modern sedimentation, in the studied oil field. It aims to systematically dissect the internal structure of sand bodies within the sand unit of a gravity flow channel. This study includes a detailed analysis of the stacking relationships and spatial distribution patterns between sand bodies at different hierarchical levels. Furthermore, it aims to establish a distribution model for gravity flow channels. The findings of this study will provide important guidance for the detailed research of lacustrine gravity flow channel reservoirs and the further development and adjustment of oil fields.

2. Geological Background

2.1. Geographical Location

The Banqiao Depression is a secondary subsidence developed on the slope of the Qikou Main Basin. It is bounded by the Cangdong Fault to the northwest and connected to the Beidagang–Qianshan tectonic zone to the southeast. It is a fan-shaped fault depression complex that has been structurally uplifted by a series of NE- and NNE-trending faults, with complex fault interactions in the northwest and southeast directions (Figure 1a). The study area is located in the main part of the Banqiao Depression, which is dissected by three secondary faults (the Banqiao, Dazhangtuo, and Baishuitou Faults) into the following four regions: Banbei, Banzhong, Bannan, and Baishuitou. The overall structure is a step-by-step uplift from the Banbei–Banzhong–Bannan blocks, with an area of approximately 220 km² (Figure 1b).

Drilling has revealed that the oil-bearing intervals in this area mainly belong to the Shahejie and Dongying Formations. Among them, the lower member of the Shahejie Formation is a typical gravity flow channel deposition environment, with an average sand thickness of about 400 m [18]. Its proven geological reserves account for more than 50% of the total reserves, and represent the main production intervals, in this oilfield. Some scholars have conducted related research on the characteristics and controlling factors of gravity flow channel sedimentation in the Banqiao area [19–21], but their focus has been mainly on the macroscopic sedimentary patterns, and there is still limited knowledge about the internal structural characteristics and distribution patterns of gravity flow channels.

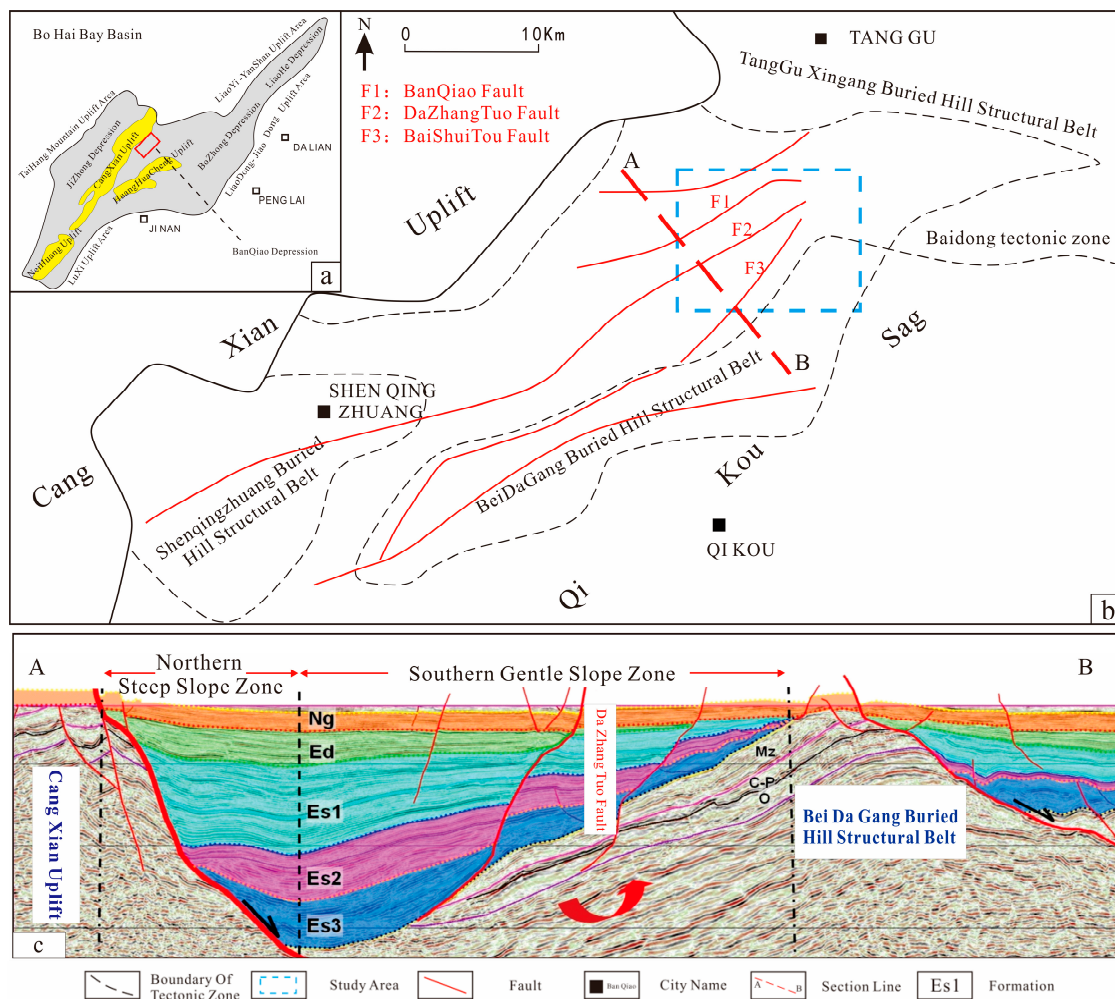


Figure 1. (a) Location map of the Huanghua Depression. (b) Location and fault distribution of the Banqiao Oilfield. (c) Structural section of the Banqiao Oilfield. A, B is the seismic cross-section of the connecting line in Figure (b) (From Huang Chuanyan [18]).

2.2. Regional Sedimentary Features

During the deposition of the lower member of the Shahejie Formation in the Banqiao Oilfield, the basin experienced deepening and expansion due to the activities of secondary faults in the area. The sediment supply was relatively limited, resulting in under-compensational sedimentation [22]. The strong extensional faulting created a larger accommodation space in the basin than the sediment supply, leading to dominant sedimentary processes, such as gravity collapse, slump, and channel avulsion, which formed typical gravity flow channel deposits in the area [19]. The sedimentary sources in the area mainly come from the northeast and northwest directions. The northeast source is mainly carried by the Yanshan river system and is not trapped by the Beitang Sag, resulting in the formation of a fan-delta deposition in the northeast direction outside of the oilfield. Due to gravity, these sediments are transported further into the Banqiao Sag. The northwest source represents the terrestrial clastic source area, mainly from the Xiaozhan area. Due to the steep paleotopography at the basin margin, and the proximity to the source, large amounts of terrestrial clastics are directly transported into the lake via floods. The high-density floods, combined with the slumping of coastal sediments, formed a nearshore subaqueous fan in the northwest direction outside of the Banqiao Sag. These sediments then rapidly flow into the Banqiao Sag, forming gravity flow channel deposits. The sedimentation process is characterized by abundant sediment supply, fast accumulation rates, and seasonal or catastrophic variations in sediment supply (Figure 2).

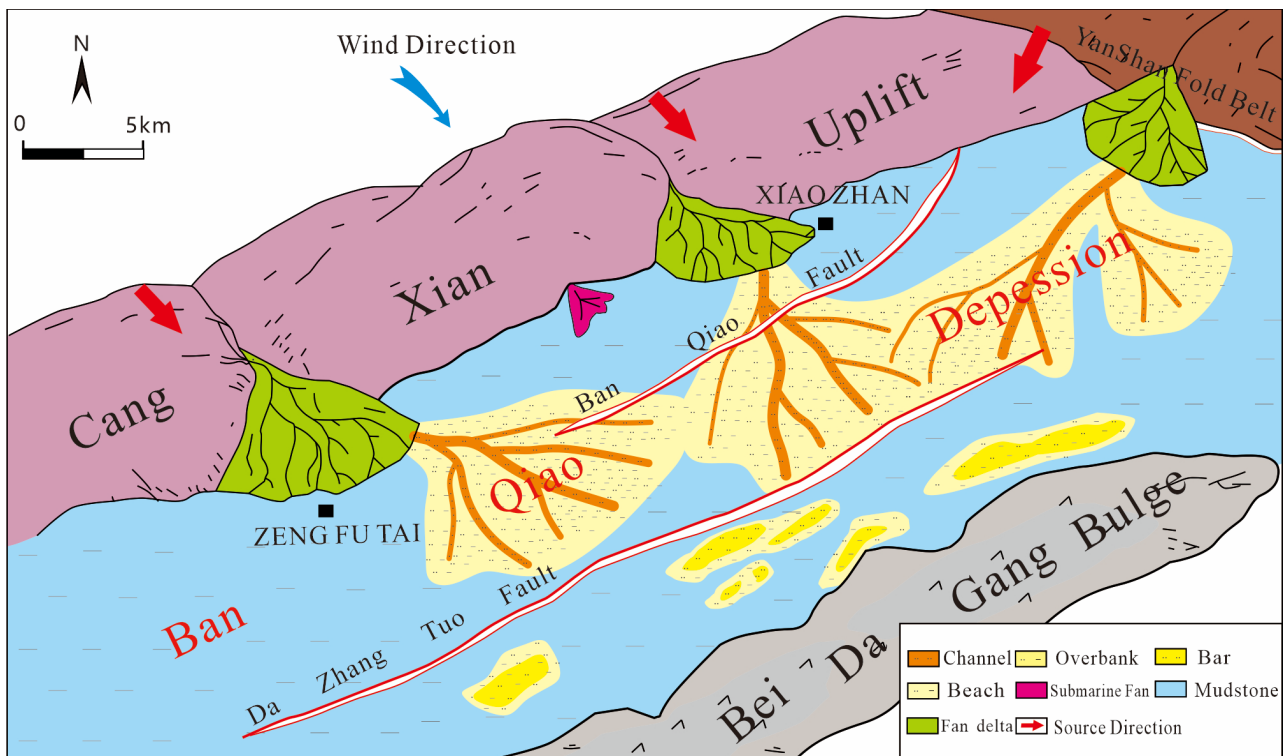


Figure 2. Sedimentary environment of the first member of the Shahejie Formation in the northern part of the Huanghua depression. (From Shi Shige [19]).

3. Data and Methods

3.1. Data

This study utilized more than 100 wells, with well spacing ranging from 100 to 300 m, resulting in a high well network density (Figure 3). The seismic data covered approximately 1000 square kilometers, with a dominant frequency of around 30 Hz. In total, 116.3 m of core samples were collected, and 10 erosion surfaces, representing the boundaries of 10 sand bodies, were identified. Due to data confidentiality, the well numbers and planar coordinates were altered and concealed.

3.2. Methods

3.2.1. Core Analysis

A systematic observation of 15 core samples, totaling 200 m in length, was conducted. The core samples were wiped with water to remove surface dust, making various sedimentary features more apparent. Special lithologies, and the locations of lithological transitions within the core sections, were carefully observed, described, and photographed, with their transition depths recorded. Upon returning to the laboratory, a core log was constructed, based on the recorded core data, and the depth information was calibrated using well log curves to obtain more accurate depth information.

3.2.2. Seismic Attributes

The original seismic data were processed using MATLAB 2023 software to enhance the seismic main frequency. Subsequently, Petrel 2018 software was utilized to extract amplitude-based and energy-based seismic attributes [20–25]. By comparing the correlation between seismic attributes and sand thickness, the RMS attribute that showed a higher correlation with the sand bodies was selected to characterize the boundaries of the sand bodies.

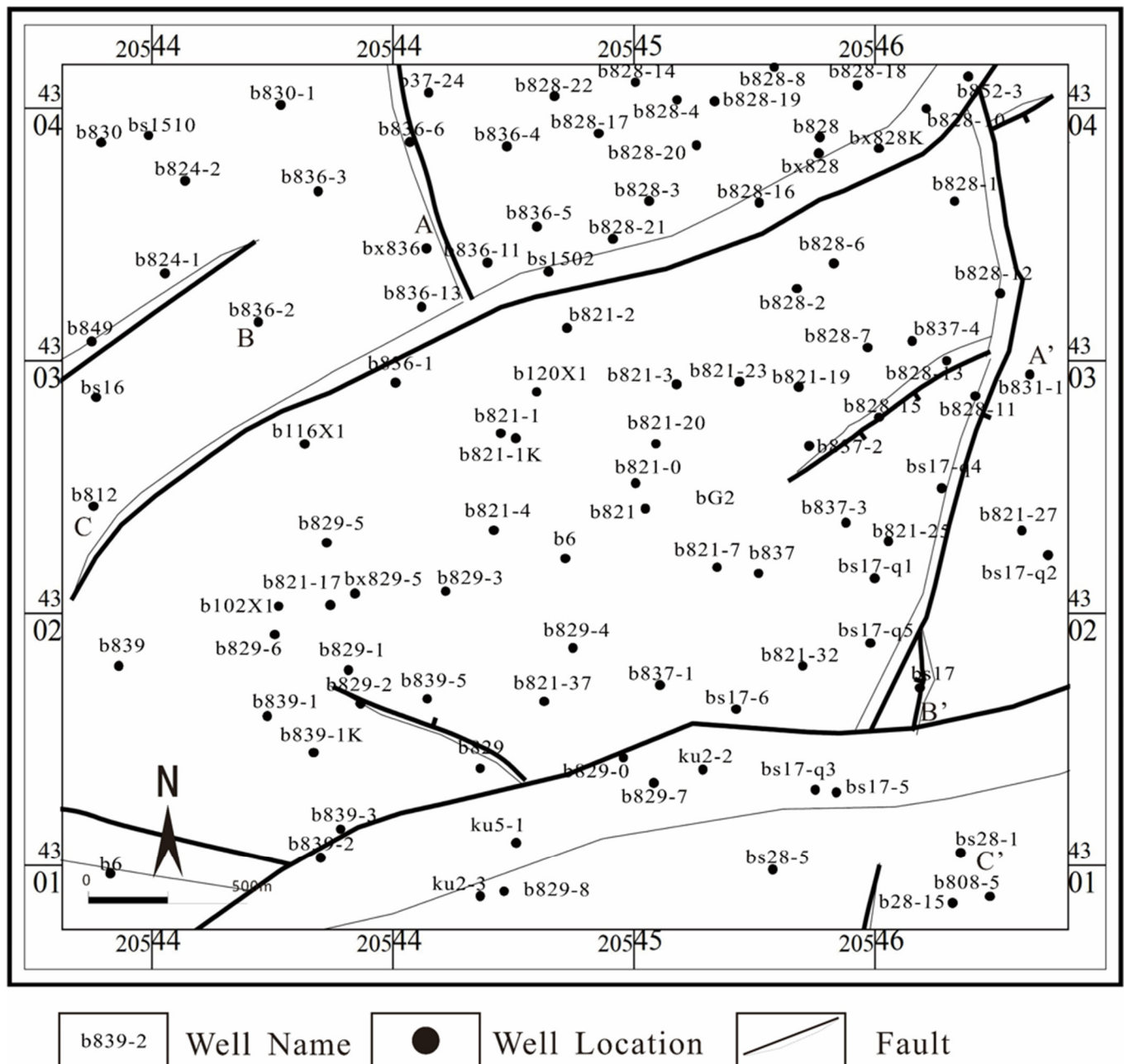


Figure 3. Study area well location map.

3.2.3. Tracer Test

Tracers such as $1.5 \text{ Ci } ^3\text{H}$, NH_4NO_3 , and ^{35}S were injected into the injection well. The water displacement velocity in the injection well, the date of initial tracer appearance in other oil wells, and the distance between the oil wells and the injection well were recorded. The connectivity of sand bodies between the wells was determined by analyzing the tracer display in the oil wells, allowing for determination of the sand body distribution pattern.

4. Results

4.1. Sedimentological Outline

By observing the core samples from the well, sedimentary structures, such as slumping structures, Bouma sequences, and liquefaction pipes, can be observed and are considered strong evidence of gravity flow deposition [21–26]. Mudstone is mainly deep gray in color, with stable distribution and the characteristics of high purity and low organic matter con-

tent. Sandstone layers, with blocky bedding, are commonly found in thick mudstone units (Figure 4). The sandstone is predominantly fine-grained sandstone, followed by siltstone. Individual sedimentary units are mainly characterized by normal grading and incomplete development of Bouma sequences, with B, C, and D segments being the most common.

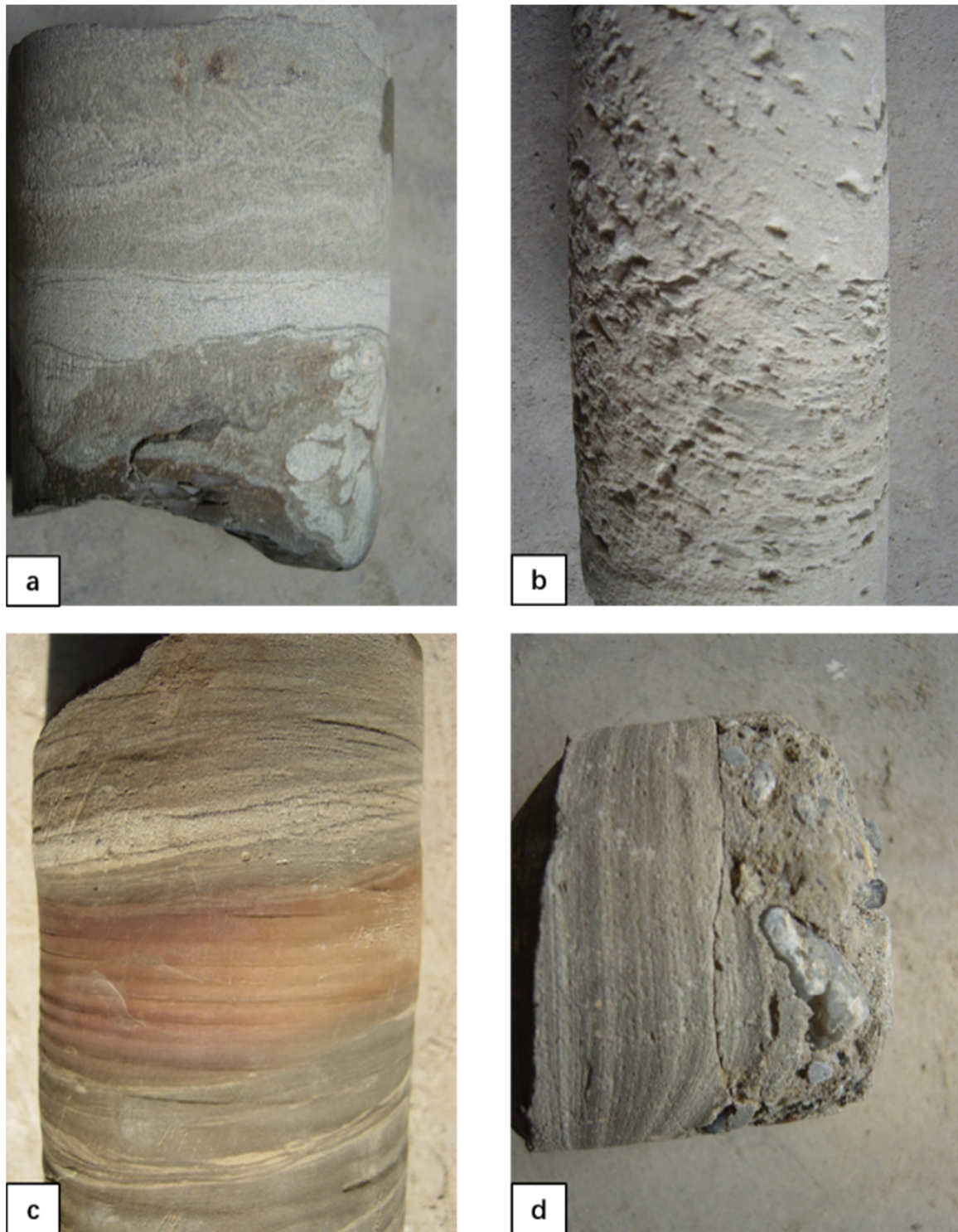


Figure 4. Core photo map: (a) 3322.2 m slump and deformation structure in well Ban 837; (b) 3002.7 m bioturbation effect of the b884 well; (c) the b839-2 well 2887.8 m Bouma sequence; and (d) 3348 m gravel bottom scour surface of the b884 well.

4.2. Sand Body Boundary Characterization

Seismic attributes are commonly used to highlight the characteristics of channel sand bodies [27,28]. RMS amplitude attributes were extracted along the top surfaces of each reservoir unit as isochron constraints (Figure 5). By calibrating the RMS amplitude slices with lithology information from the core samples, yellow and dark green areas on the slices corresponded to gravity flow sandstone, while the blue-green areas indicated sand–mud transitional deposits [29]. Based on this, the boundaries of the gravity flow sand bodies were delineated.

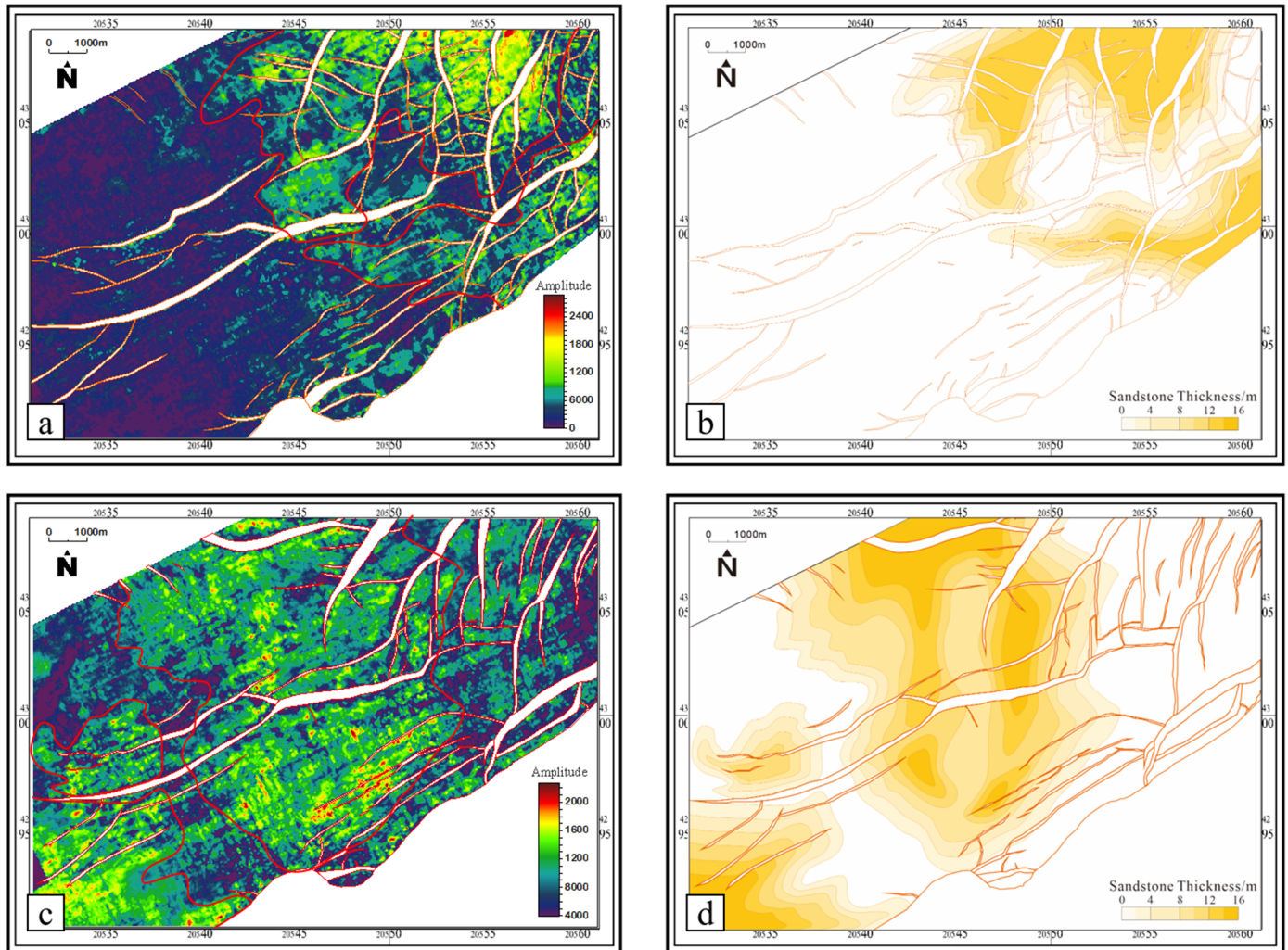


Figure 5. Attribute slice and sand body thickness map: (a) Ban 1 Sublayer RMS property slicing; (b) thickness map of a small layer of the sand body on ban 1; (c) Ban 4 Sublayer RMS property slicing; and (d) thickness map of a small layer of the sand body on ban 4.

4.3. Single Channel Identification

The primary challenge in reservoir characterization is identifying and describing the internal configuration of a single water-bearing sand body within a given time unit (sub-layer or sand unit) using drilling data [30]. This forms the foundation for the subsequent analysis of the internal configuration of the single water-bearing sand body.

4.3.1. Sedimentary Phase Sequence Characteristics

According to the lithological characteristics of the gravity flow channel sand body, and the differences in sedimentary locations, the channel was divided into the following two subfacies: the main channel subfacies and the floodplain subfacies. The main channel

subfacies is the most important constituent unit of the gravity flow channel reservoir, and it can be further divided into the channel center microfacies and channel flank microfacies. Due to the influence of changes in the reference plane, the electric logging curves of the floodplain subfacies often show high-amplitude tooth shapes or “sharp knife” shape combinations, with the tooth centerline being relatively horizontal, reflecting the sedimentary characteristics of interbedded sand and mud. The sand body of the main channel subfacies is thicker, and the electric logging curves show large amplitude anomalies, with the main curve shapes including box-shaped, bell-shaped, and funnel-shaped curves (Figure 6). In the study area, the gravity flow channel sand body are mainly characterized by positive cyclicity, and the electric logging curves mainly reflect box-shaped patterns, with larger thickness and higher amplitude. The top of the sand body often transitions to a bell-shaped pattern, and it is commonly in contact with mudstone transitions, corresponding to the sedimentary transition from coarse-grained to fine sandstone, siltstone, and eventually to lacustrine mudstone.

4.3.2. Vertical Identification Signs

If similar wells encounter water channel sand deposition, in order to determine whether they belong to the same water channel sand body, the following six identification criteria for a single water channel are summarized through the study of the phase change characteristics, curve morphology differences, interbedding number, etc., of a single water channel:

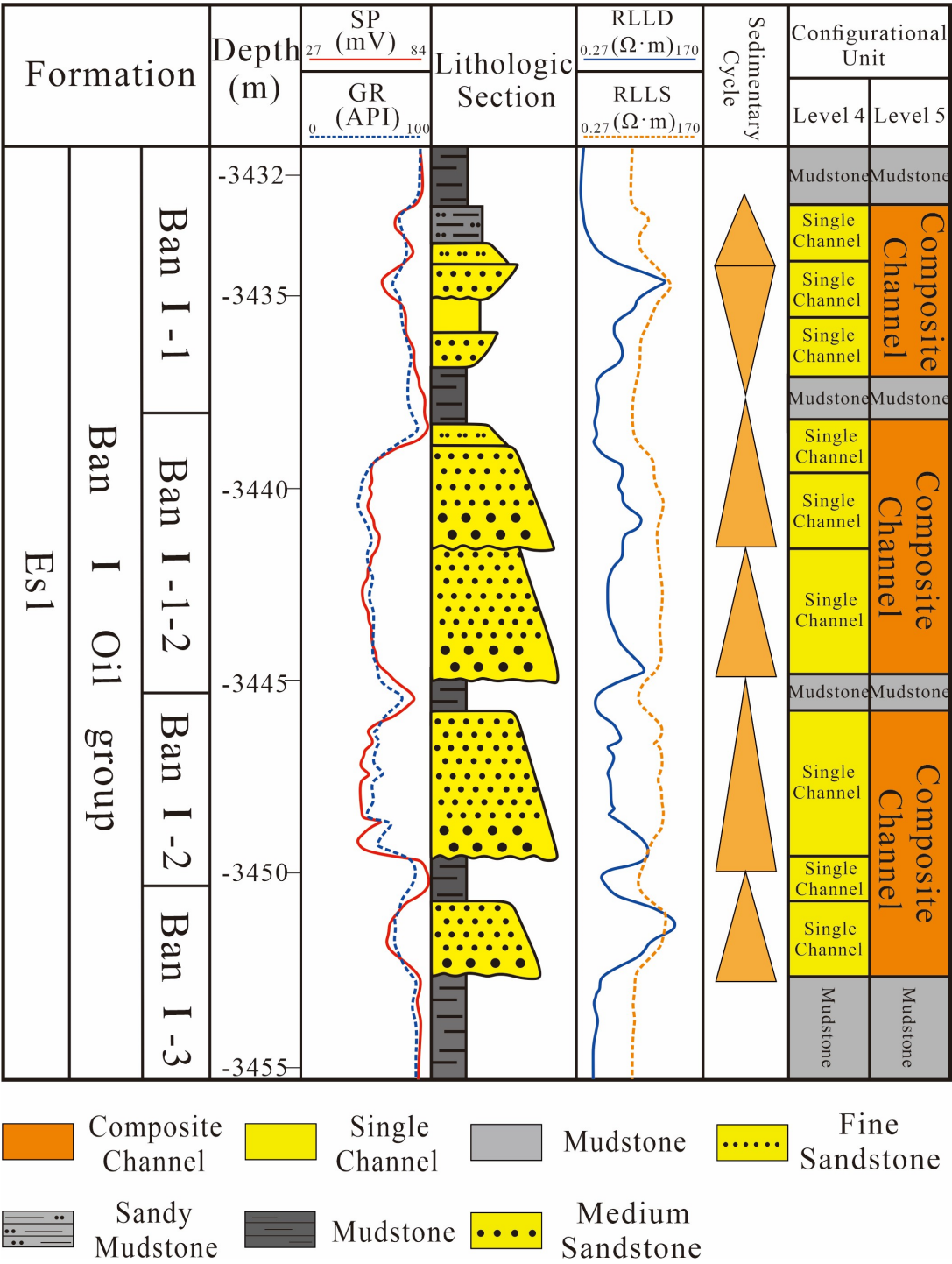
(1) The interbedding of mudstone between water channels. The scouring and down-cutting of gravity flow forms local depressions in the topography, and the flow of water in the water channel becomes turbulent, indicating a high-energy environment, while the area between two water channels is a deepwater, low-energy environment, which is filled with fine-grained muddy sediment, forming interbedded mudstone between water channels. The development of interbedded mudstone between adjacent water channels can be taken as direct evidence for distinguishing different single water channels on the plane (Figure 7a).

(2) The deposition of overbank sand between water channels. In the gentle slope zone, the erosive action of gravity flow is weakened, and the water level is higher than the topography. The sediment carried by the water flow scatters and forms fan-shaped overbank deposition around the water channel sand. Therefore, if overbank deposition is encountered during drilling, it can be taken as a direct indication of the boundary of water channel sand deposition.

(3) Differences in logging curve morphology. Water channels of the same period, with relatively stable hydrodynamic environment and lake level changes during deposition, will have similar responses on the logging curves. If the logging curves of adjacent wells show significant differences in morphology, it can be inferred that they belong to different single water channel deposits (Figure 7b).

(4) Differences in relative elevation between adjacent water channels. A relative elevation difference at the bottom of the water channel sand body represents an altitude difference in the paleogeomorphology during deposition. In the gentle slope zone (especially in the central area of the basin), the paleogeomorphology is relatively flat during the deposition of water channel sand bodies within a certain range (well spacing). If there is a large relative elevation difference between the bottoms of the sand bodies in adjacent wells, it is highly likely that they do not belong to the same water channel sand body (Figure 7c).

(5) Mismatched interbeds within water channels. The development of interbeds within water channels, to some extent, reflects the hydrodynamic conditions during deposition, as well as the supply of clastic materials [31]. The number of interbeds within the same water channel sand body should be roughly the same, and significant variations in the numbers of interbeds in adjacent single water channels indicate the possibility of different single water channels.



(6) Dynamic data revealing disconnection. Dynamic data (tracer tests, polymers, etc.) are powerful sources of evidence for determining the connectivity of sand bodies. Each channel sand body is an independent connected entity, and if dynamic data confirm that the sand bodies are disconnected, these results indicate that they do not belong to the same sand body or the same single channel.

In addition, different channel sand bodies may also differ in sedimentary rhythm, development thickness, etc., which can serve as auxiliary evidence for distinguishing a single channel. By comprehensively using these indicators and combining them with the

combination morphology on the plane, the boundary of a single channel can be accurately identified in a complex channel sand body.

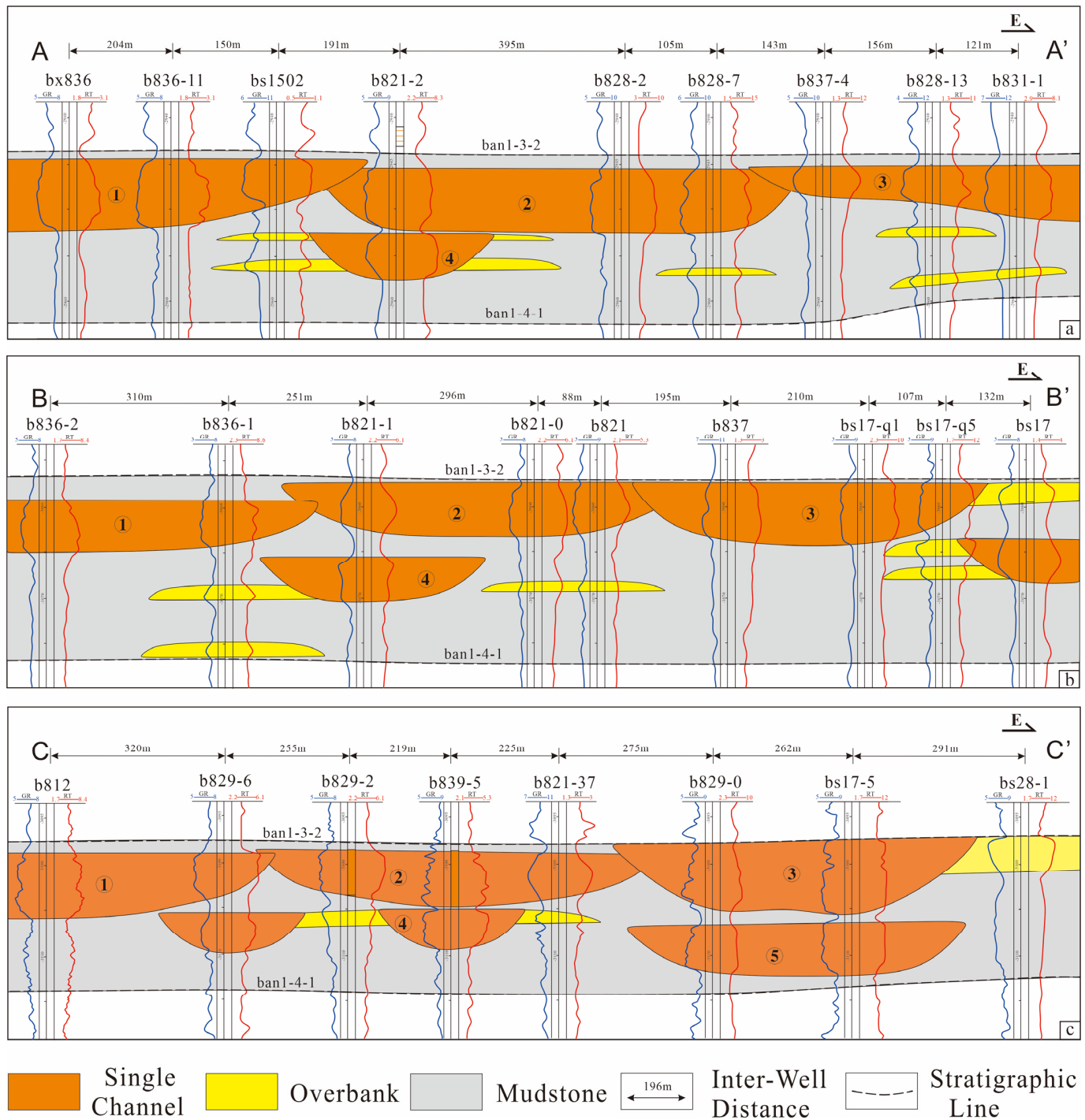


Figure 7. Single channel identification and division in the B886 well area of the Banqiao Oilfield (see Figure 8b for the AA'/BB'/CC' section position). (a) The interbedding of mudstone between water channels; (b) Differences in logging curve morphology; (c) Differences in relative elevation between adjacent water channels.

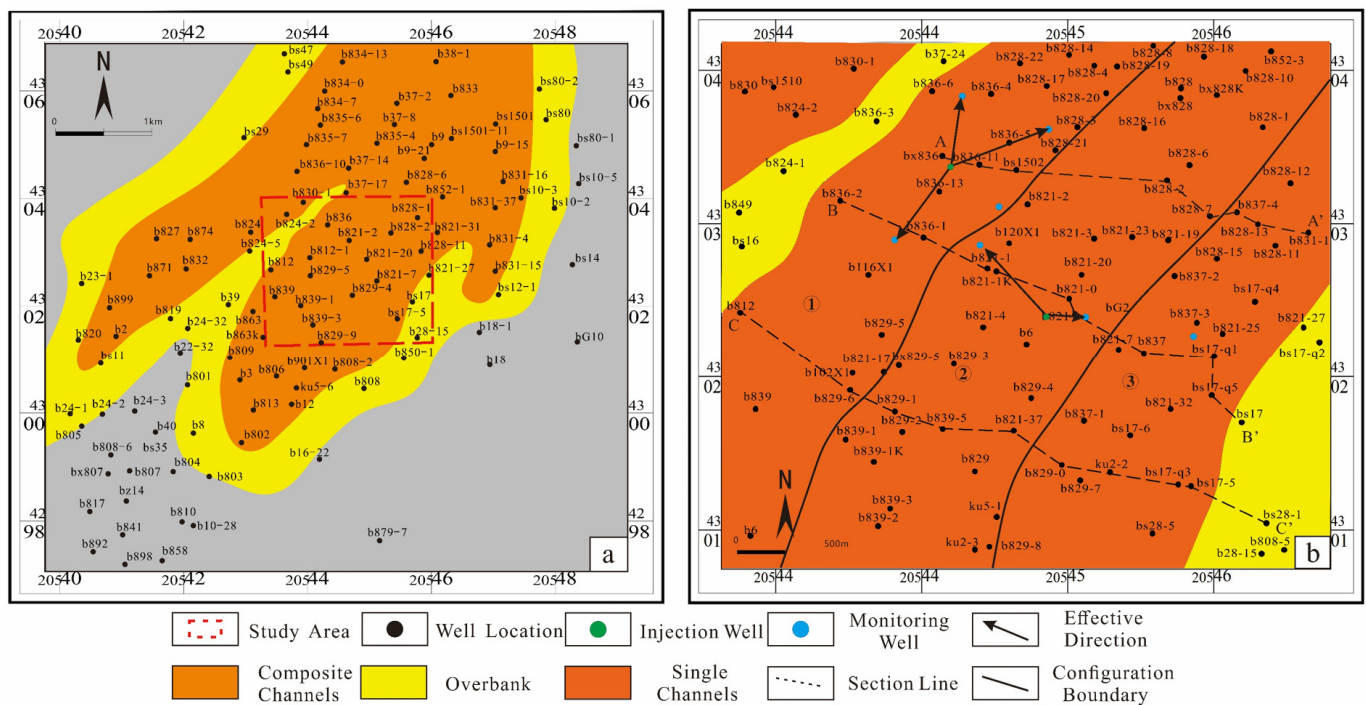


Figure 8. Single bar division and distribution in the ban 1-4-1 single sand layer of the Banqiao Oilfield. (a) Composite channels boundary; (b) Single channel boundary.

4.4. Single Channel Characterization

Based on the method of identifying a single channel within a single channel, take the b821 well area, ban 1-4-1 single sand layer as an example. By using three intersecting cross-sections in the vertical direction of the channel (profiles a, b, and c), the composite channel sand bodies are identified and divided into three single channels from the same period. Channels ①, ②, and ③ belong to the same period, but different position combination patterns, which means they are three different single channels deposited during the same period. Channels ①, ②, and ③, along with channels ④ and ⑤ belong to the same layer, but different period combination patterns, which means they were vertically superimposed during different periods (Figure 8a).

The division results were verified using dynamic data. In the b821 injection well group, two monitoring wells, b120X1 and bG2, both showed 3H tracers from oil injection well b821 during the monitoring period (Table 1). These three wells belong to the same single channel (channel ②), indicating good sand body connectivity. Monitoring wells b836-1 and b821-25, which belong to channel ① and channel ③, respectively, are different single-channel depositions from the injection well b821 (channel ②). No tracer was observed during the monitoring period, indicating poor connectivity between the injection well and these wells. Similarly, in the b836-11 injection well group, three monitoring wells, b836-4, b836-1, and b828-3, all observed 3H tracers from the oil injection well, b836-11, during the monitoring period. These four wells belong to the same single channel (channel ①), indicating good sand body connectivity. Monitoring well b821-2 belongs to channel ② and is in a different single-channel deposition from injection well b836-11 (channel ①).

No tracers were observed during the monitoring period. The dynamic data validation proves that the division results of the single sand layer's internal single channel are accurate and reliable. The single channel distribution map of the layer is formed by identifying and dividing each composite channel sand body into single channels (Figure 8b).

Table 1. Tracer dynamic data table.

Injection Well	Monitoring Well	Well Spacing (m)	Number of Days (d)	Speed of Water Injection (m/d)
b836-11	b836-1	248	108	2.3
	b828-3	365	172	2.12
	b836-4	278	257	1.08
	b821-2	241	/	/
b821	b120X1	430	5	86
	bG2	550	5	110
	b836-1	850	/	/
	b821-25	500	/	/

5. Discussion

5.1. Gravity Flow Channel Depositional Architectural Patterns

By studying the identification and division results of individual channels within the complex channel system, the different spatial distribution patterns of sand bodies can be observed in different structural parts (or different blocks), which can be mainly classified into the three following types: the lateral migration, vertical superposition, and isolated types [32].

(1) The lateral migration type refers to the lateral splicing of multiple individual channels in the same layer and within the same period (Figure 9). The relative elevation difference between individual channels is not obvious, but their curve shapes, the number of internal interlayers, and the scale of individual channels may vary. In the northern part of the board, it is “trapped” between the Cangxian uplift and the Banqiao Fault, with steep and complex terrain, as well as the development of faults and related associated structures. Gravity flow channels, which developed along the steep slope, tend to be forced to change their course laterally when encountering obstacles (positive microtopography), and the flow direction of channels changes significantly [33–35]. The related structures formed by the Banqiao Fault led to a certain elevation difference between the two plates, usually restricting the distribution of channels. However, under certain conditions, gravity flow channels can cross faults and related associated structures, and their directions also change accordingly. At the same time, gravity flow channels are also constrained, to a certain extent, by being limited to a negative microtopographic unit, which affects their orientations. Although detrital sediments can continue to be transported, it is difficult for them to break through the boundaries on both sides of the negative microtopographic unit and change their original flow direction, instead continuing to move forward along the negative microtopography.

The rise and fall of the lake levels cause frequent changes in different wave energy zones and, combined with intermittent wave action of different strengths, may also result in the spatial distribution pattern of overlapping and lateral migration of gravity flow channels [36]. When the lake level slowly decreases from a high point, the wave base drops accordingly and touches the lake bottom, causing the gravity flow channels to oscillate and migrate due to the actions of lake waves.

(2) The vertical superposition type refers to the vertical accumulation of multiple single-channel deposits from different periods [37,38]. Each single channel has distinct elevation differences, and generally thicker sedimentary thickness, showing a vertical continuous stacking of thick channel sands in the same region. This type of single-channel combination pattern is mainly distributed in the southern part of the interblock in the basin. Multiple core wells (such as the b821 and b821-0 wells) have confirmed that the basin area is “trapped” between the Dazhangtuo Fault and the Banqiao Fault. The local adjustment hub of the Dazhangtuo Fault will promote the sediment distribution of the sand bodies, resulting in obvious thickening trends of the local sand bodies near the fault step zone and providing a material basis for gravity flow channel deposition. The steep slope in the cross section hinders the gravity flow channel, forming a locally sustained high-

energy hydrodynamic environment, which unloads a large amount of sediment, carried by the flow. At the same time, the fragmented particles unloaded at the cross section tend to slide and fall, due to the increase in gravitational force. On the other hand, the flow of gravity is obstructed by the Banqiao Fault and its related associated structures, the flow energy attenuates, and the basin area has a gentle tectonic setting, weakening the erosion of the flow and enhancing the deposition. The channel tapers out towards the basin, and subsequent episodes of strong energy gravity flows continue to erode along the original channel, thus promoting the formation of the continuous vertical accumulation of single-channel sand bodies in the local areas.

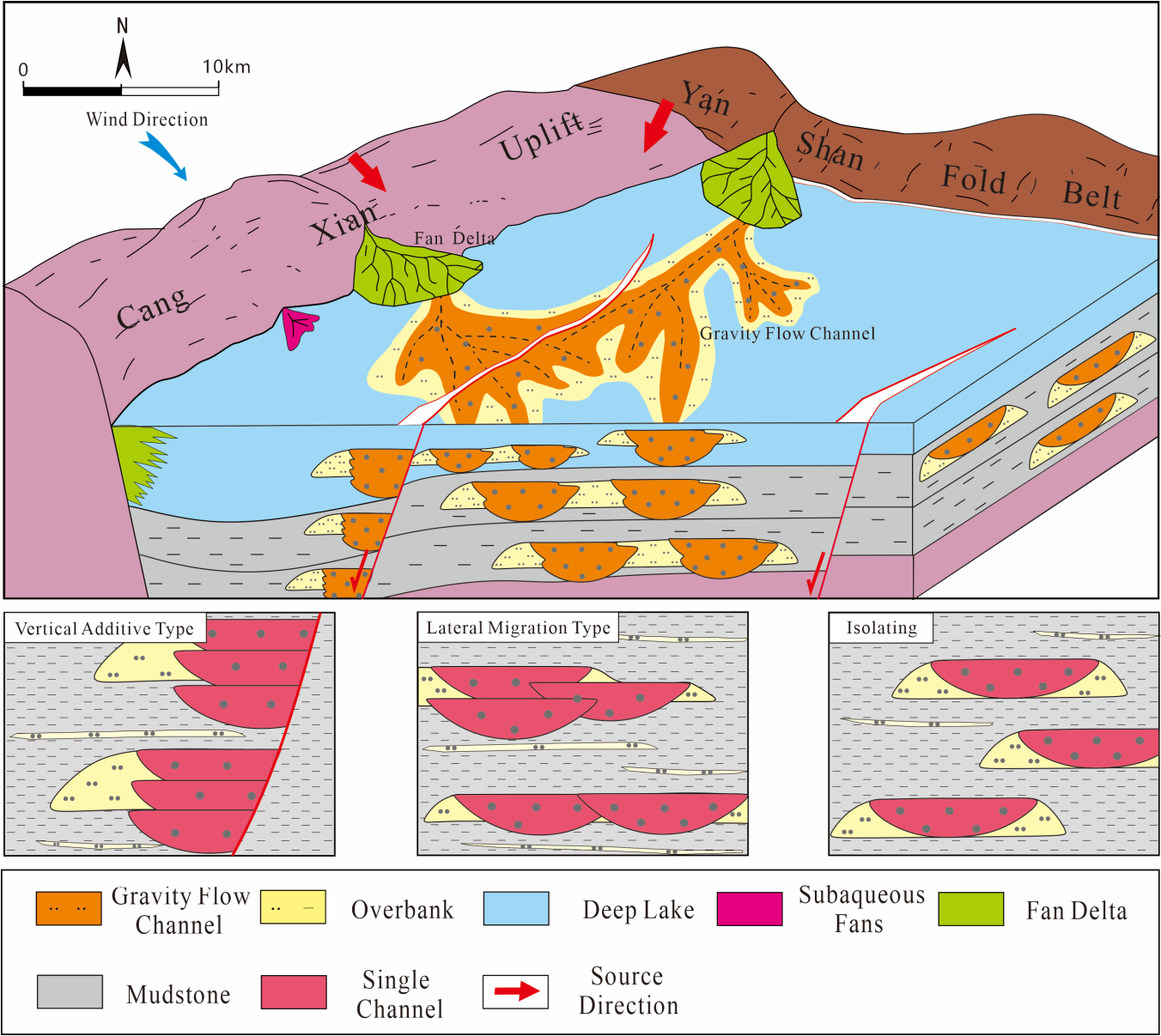


Figure 9. Distribution model of gravity flow channels for Es1 in the Banqiao Oilfield.

(3) The isolated type shows the isolated distribution of different single-channel sand bodies, usually with lateral and vertical transitions, i.e., adjacent to overflow sand or mudstone. This type of channel sand body is mainly distributed in the northern region of the steep slope zone. Due to their proximity to the source, gravity water flows carry large amounts of sediment into the lake [39,40]. The water flow is strongly affected by gravity and has a deepwater body. Most of the source sand bodies are located below the wave

base and are rarely modified by the lake waves, leading to the development of isolated gravity flow channel sand bodies in this region. The scale of each single-channel sand body is relatively small, and its distribution range is limited.

5.2. Single-Channel Quantitative Parameter Analysis

A statistical analysis was conducted on the selected parameters of gravity flow reservoirs in different global regions (Table 2). The results indicate that gravity flow sediments exhibit diverse spatial distribution patterns, characterized by coarse grain size and low matrix content. Generally, gravity flow sediments possess larger width-to-thickness ratios, but the reservoir properties are relatively poor. Therefore, we have meticulously characterized the quantitative parameters of single-channel gravity flow pathways.

Table 2. Comprehensive evaluation of the reservoir properties of different gravity flows.

Shape	Grain Size	Length (km)	Width-to-Thickness Ratio	Area	Source
Tongue-like	Medium- to coarse-grained	6~7	150~180	Banqiao Oilfield, China	This study
Banded	Fine- to medium-grained	18~67	110~130	Ordos Basin, China	Qiqi LYU [11]
“W” shape	Medium- to coarse-grained	/	About 10	Congo Fan Basin, West Africa	Hua CHEN [41]
High camber	Fine- to medium-grained	180~200	10~20	Yinggehai Basin, China	Zengbo Hui [42]
Low camber	Medium- to coarse-grained	/	20~30	Rovuma Basin, East Africa	Jiajia Zhang [43]

5.3. The Application of Architectural Patterns in Oilfield Exploration and Development

Frequent channel shifting in the Banqiao Oilfield poses challenges in accurately characterizing the reservoir during field development. The stacking relationships and patterns of sand bodies constrain their connectivity, highlighting the importance of fine reservoir characterization for guiding oilfield development and production. Based on the detailed division of single channels, a statistical analysis was conducted on 228 single-channel sand bodies, controlled by 764 well points in the ban 1 to ban 4 oil zones. The average length of the sand bodies was 6627.5 m, the average width was 722.5 m, the average thickness was 5.44 m, and the average width/thickness ratio was 177.34. There was a good correlation between the average length and width of the channels (Table 3). From the statistical analysis of the long-axis direction of the 228 single-channel sand bodies, two dominant distribution directions, NNE15° and NNE50°, were identified, with NNE50° being the main direction.

Table 3. Quantitative parameters of a single bar for Es2 in the Banqiao Oilfield.

Oil Group	Channel Architectural Patterns	Single-Channel Number	Number of Control Wells	Average Thickness (m)	Average Length (m)	Average Width (m)	Average Width-to-Thickness Ratio
ban1	Isolated type	43	764	5.28	6151	664	158.19
ban2	Isolated type	42	398	5.47	6526	729	182.95
ban3	lateral migration	46	489	5.64	6954	732	178.56
ban4	vertical superposition	52	378	5.36	6879	765	189.64

Studies have shown that the stacking patterns of sand bodies in the Banqiao Oilfield are closely related to their production capacity. Sand bodies in ban 1, ban 2, and ban 4 are predominantly vertically isolated, resulting in poorer production capacities (Figure 10). In contrast, the sand bodies in ban 3 are more developed, with overlapping channel incisions

and fewer mud deposits. They exhibit a composite and laterally juxtaposed pattern, leading to better connectivity and a higher encounter rate within a single waterway (Figure 10). Overall, the composite and laterally juxtaposed sand bodies in ban 3 of the Banqiao Oilfield represent high-quality reservoirs and are promising areas for further development.

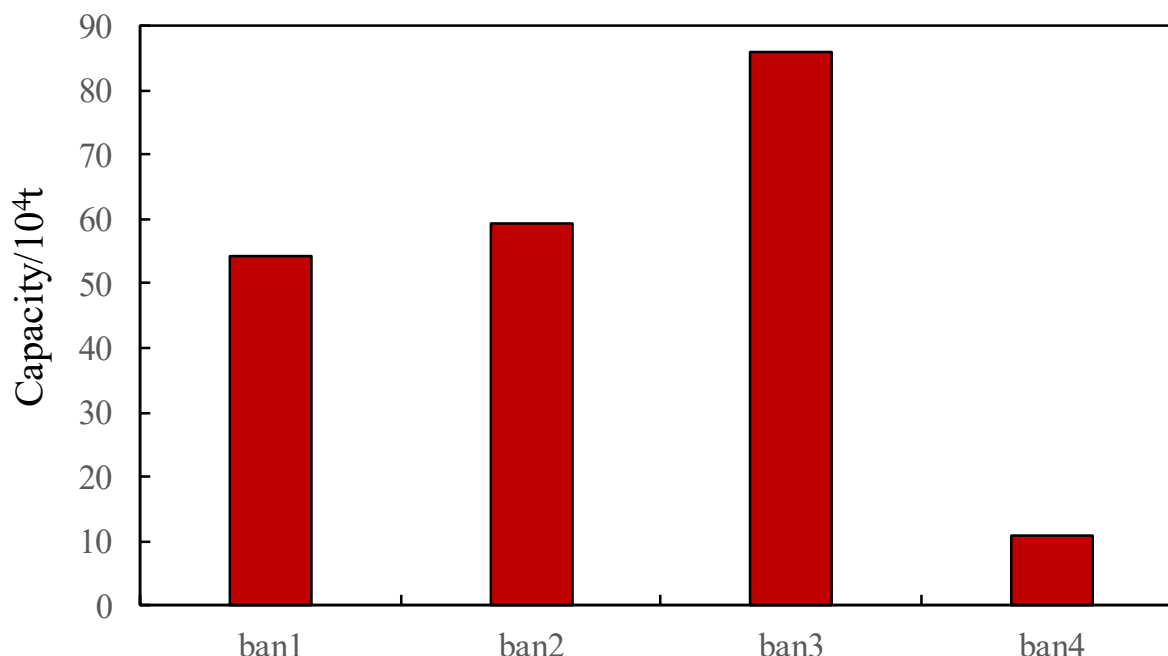


Figure 10. Histogram showing the oil group capacities of ban 1–ban 4.

6. Conclusions

This study revealed the internal sand body structure and deposition patterns of gravity flow channels and allowed us to draw the following conclusions:

(1) The reservoirs of gravity flow channels in the study area are mainly divided into main channels and channel margins. The analysis of well network data showed that the log curves of the main channels exhibit box-shaped and bell-shaped patterns, with greater thickness. On the other hand, the channel margins exhibit funnel-shaped patterns with less thickness. However, the development of gravity flow channel reservoirs in all locations shows incomplete Bouma sequences.

(2) The spatial distribution of gravity flow channel reservoirs can be predicted using seismic attributes and well log data. The RMS attribute provides more accurate prediction of inter-well sand bodies, and well log interpretation has higher vertical resolution. The prediction results of gravity flow channels are more accurate compared to the actual subsurface conditions, but they are influenced by the interpretation results of seismic attributes and well network density.

(3) Based on the detailed subdivision of individual channels, a total of 228 individual channel sand bodies, controlled by 764 well points, were statistically analyzed. The average length of the sand bodies is 6627.5 m, the average width is 722.5 m, the average thickness is 5.44 m, and the average width/thickness ratio is 177.34. It was found that, the greater the average width of the channel, the greater the average thickness of the channel.

(4) Research on submarine gravity flow channels is still in the exploratory stage. Although many scholars have conducted extensive work on the descriptions of subsurface reservoirs based on core samples, outcrop observations, and laboratory simulation experiments, there are still many questions worth considering. Firstly, the scale of gravity flow channels formed in different sedimentary environments varies, and there is significant variation in previous predictions of channel configuration and scale. Therefore, the findings of previous studies may not necessarily be applicable until the sedimentary environments

of the gravity flow channels are clearly understood. Additionally, gravity flow channels are known to have poor stability, and they can be easily modified. Hence, it is worth considering whether it is appropriate to rely solely on modern sedimentary parameters to guide the study of subsurface reservoir architecture.

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