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# The Architecture Characterization of Braided River Reservoirs in the Presence of Horizontal Wells—An Application in a Tight Gas Reservoir in the North Ordos Basin, China

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**Abstract:** The study of the reservoir architecture in braided river systems has significant implications for the exploitation of remaining oil and gas reserves. However, due to the complexity of the braided river deposition process, the architecture patterns are diverse and intricate. Limited by the quality of seismic data and well network density, the characterization of underground reservoir architecture often entails considerable uncertainty. This paper investigates the architecture elements, stacking patterns, and significance of oil and gas development in the braided river deposition of the Jin 58 well area in the northern part of the Ordos Basin through typical field outcrop and core observations, and by making full use of horizontal well data. The study reveals that the Jin 58 well area is mainly characterized by four types of architecture units: braided channel, channel bar, overbank, and flood plain. Based on the data from horizontal and vertical wells, four identification criteria for single sand bodies are determined, and the vertical stacking and lateral juxtaposition styles of the architecture units, as well as the architecture patterns and internal features of the channel bar, are summarized. It is confirmed that composite sand bodies have better productivity. A three-dimensional architecture model of the braided river is established based on the results of architecture analysis. The accuracy of the architecture analysis is validated through numerical simulation, providing a basis for subsequent well deployment and other related activities.

**Keywords:** Ordos Basin; Jin 58 well area; braided river deposition; reservoir architecture; three-dimensional architecture modeling; numerical simulation

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## 1. Introduction

A braided river is a highly significant type of continental sedimentary system, characterized by relatively flat valleys, low sinuosity, steep gradients, large flow variations, coarse clastic sediments, and frequent channel shifting. Based on the size of sediment particles, braided rivers can be divided into sandy braided rivers and gravelly braided rivers [1–3]. A sandy-gravelly braided river is widely developed in the continental basins in China, such as the Bohai Bay Basin [4], the Ordos Basin [5], and the Junggar Basin [2]. As the main architecture elements of a braided river, the braided river channel and channel bar are favorable sites for hydrocarbon accumulation.

Reservoir architecture refers to the shape, scale, direction, and stacking relationship of units composed of different-level reservoirs [6], and was first proposed by Miall (1985). Reservoir architecture has a significant impact on the physical properties of reservoirs and the distribution of hydrocarbons. Many domestic and foreign scholars have conducted extensive research on fluvial depositional systems, with a higher level of research on meandering river reservoir architecture. For instance, research has been conducted on architecture subdivisions, point bar analysis, architecture modeling, and the establishment of geological knowledge bases [7–14]. However, the complex sedimentary processes and ambiguous sedimentary interfaces of sandy-gravelly braided rivers have increased the difficulty of identifying reservoir architecture interfaces, making the fine study of braided river reservoir architecture one of the challenges faced by geologists both domestically and internationally [15–17]. At present, scholars have made significant progress in studying the characteristics of braided river architecture [17–20], interbedded layers [21,22], and three-dimensional architecture modeling [2,6] using field outcrops, dense well networks, modern sedimentary data, and other sources of information. However, in areas with larger well spacing, the density of the well network limits the interpretation of inter-well information, resulting in multiple interpretations and uncertainty regarding the scale and distribution characteristics of the architecture. Horizontal wells have a longer lateral extension and encounter more architecture units, providing rich lateral information and the ability to locate architecture boundaries. Therefore, the use of horizontal well data for reservoir architecture analysis has greatly reduced the uncertainty in predicting the scale and distribution of reservoir architecture units between wells.

The Upper Paleozoic tight sandstones in the Ordos Basin are formed by the rapid accumulation of terrestrial detritus carried by rivers [23]. The frequent channel migration results in the strong heterogeneity of reservoirs [23–25], making it extremely challenging to accurately characterize and predict the fine-grained sand bodies, thereby hindering breakthroughs in oil and gas production. Researchers such as Li Yilong [26], Qi Rong [27], Yu Xinghe [28], and Sun Tianjian [22] have conducted exploratory studies from field outcrops, sedimentation, architecture scale, and stacking relationships, which have promoted the development of tight sandstone gas reservoirs. However, the complex stacking relationships of braided river channel sand bodies in the northern part of the Ordos Basin and the limited research on the stacking relationships of single-period sand bodies within composite sand bodies make it difficult to meet the requirements of efficient field development [29]. In this study, the Jin 58 well area in the northern part of the Ordos Basin is taken as an example for architecture analysis. The Lower Shihezi Formation in this area is characterized by braided river deposition, and the horizontal well data are relatively complete. Taking into account the braided river deposition pattern, this study combines field outcrop, core, logging, and horizontal well data to conduct architecture analysis. The interface positions of architecture units are determined, the stacking patterns of architecture units in space are characterized, and embedded modeling is performed under hierarchical constraints. A spatial distribution model of the braided river reservoir architecture is established, providing a geological basis for further field development, theoretical support for the efficient extraction of remaining gas, and guidance for determining appropriate exploitation methods and fracturing production techniques in the later stage of the oilfield.

## 2. Geological Overview

The Ordos Basin is located on the North China Platform, which is a multi-cycle craton basin [30]. Its crystalline basement consists of Precambrian and Lower Paleozoic metamorphic rocks, overlain by sedimentary rocks from the Paleozoic, Mesozoic, and Cenozoic eras. It is a large sedimentary basin with abundant oil and gas prospects [31,32]. Extensive faults are developed at the margins of the basin, while faults within the basin itself are not well developed. According to its structural characteristics, the Ordos Basin can be divided into six structural units, namely the Yimeng Uplift, Weibei Uplift, Western Thrusting Belt, Tianhuan Depression, Yishan Slope, and Jinxi Folding Belt [33] (Figure 1a).

During the deposition of the Lower Shihezi Formation in the Ordos Basin, there was a strong uplift of the northern Yimeng Mountains due to the intensification of the Hercynian orogeny. A large amount of detrital material was transported from north to south into the basin. The sedimentary pattern during this period inherited that of the Shanxi Formation, with the development of alluvial fans, braided rivers, deltas, and lake deposits from north to south [31,34].

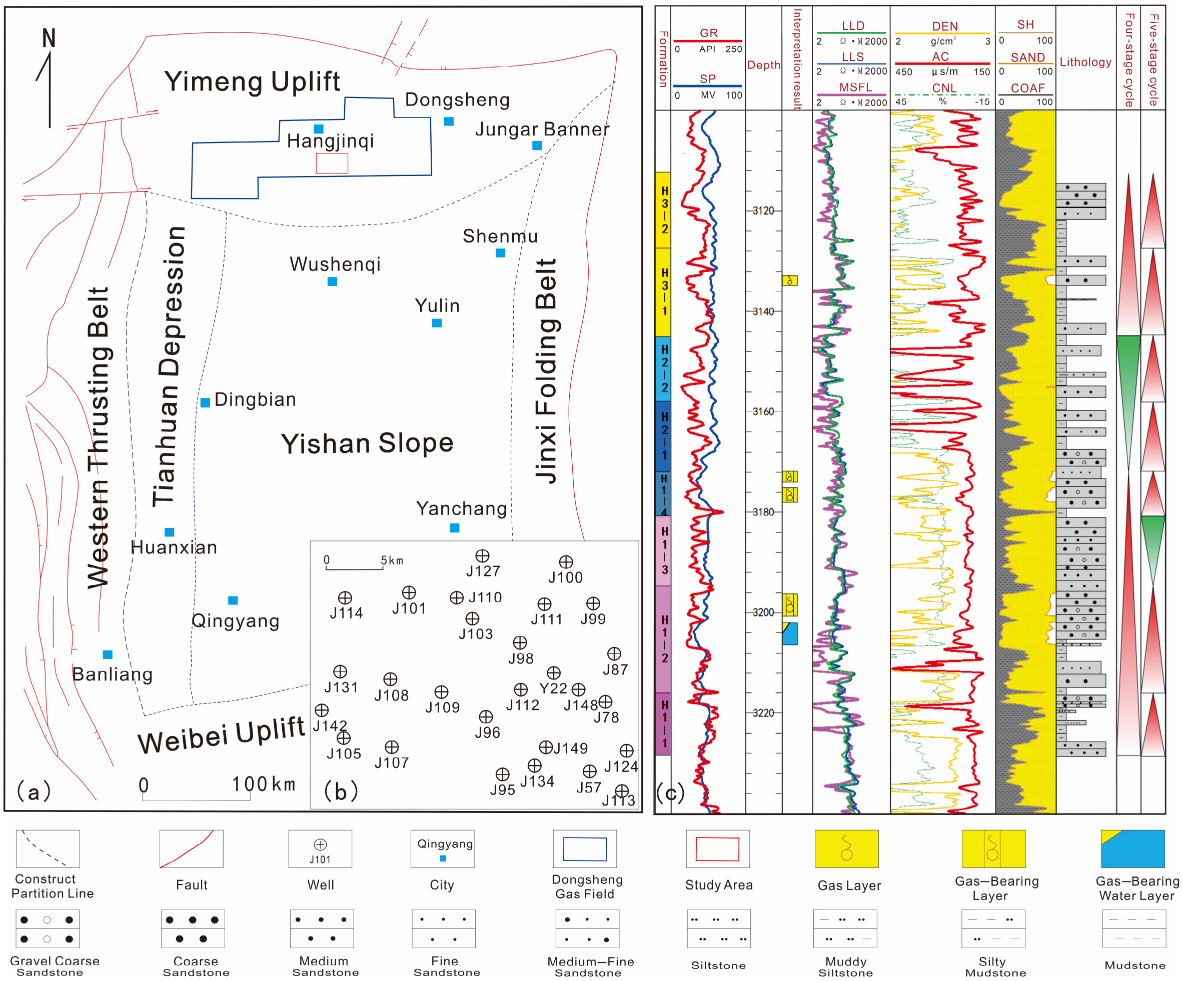


**Figure 1.** (**a**) Structural location map of the Ordos Basin; (**b**) Location of exploration wells in the study area; (**c**) Comprehensive histogram of Lower Shihezi Formation in the study area.

Hangjinqi is located on the Yimeng uplift in the north of the Ordos Basin, which exhibits a structural feature that is high in the northeast and low in the southwest. The Jin 58 well area is located in the Hangjinqi block (Figure 1), with an area of about 980 km$^2$, and develops Archean, Proterozoic, Upper Paleozoic, Mesozoic, and Cenozoic strata. The Shihezi Formation under the target layer of this study develops the first member of the box, the second member of the box, and the third member of the box from bottom to top (Figure 1c). During the sedimentary period, due to the intensified tectonic activity in the northern source area of the basin and seasonal runoff, the river development reached its peak, carrying a large amount of terrestrial detrital material southward. In the study area, this resulted in the formation of gravelly braided river deposits [5,35]. The river channels frequently migrated and changed courses, resulting in a wide distribution of sand bodies. The lateral connectivity of the sediment is good, and the dominant lithologies are conglomerates and coarse sandstones [32,36–40].

## 3. Materials and Methods

Field outcrops provide valuable insights into the formation and evolution of reservoirs. Selecting suitable outcrops helps us to understand the sedimentary patterns, development history, and architecture evolution of reservoirs. In this study, a typical braided river outcrop was selected as a starting point to analyze the stacking patterns of braided river architecture units, providing guidance for subsequent reservoir architecture analysis. When analyzing the reservoir architecture in the Jin 58 well area in the northern part of the Ordos Basin, core and logging data were used to analyze the identification criteria of individual sand bodies. Combining modern sedimentation, different types of sand body stacking patterns were summarized, and architecture analysis was conducted under hierarchical constraints, providing guidance for subsequent development and production activities.

## 4. Results

### *4.1. Division Scheme and Characteristics of Braided River Reservoir Architecture Unit*

The Lower Shihezi Formation in Jin58 area is a sandy-gravelly braided river sedimentary deposit (Figure 2), which can be divided into four microfacies: braided channel, channel bar, overbank, and flood plain (Figure 3). Referring to Miall's scheme [41] for the hierarchical division of fluvial facies architecture, the fifth-order architecture unit in the study area is mainly a single river channel (braid belt), which is separated by the mudstone of the flood plain, and the fifth-order interface is the interface of channel filling sedimentation. The fourth-order architecture unit is mainly composed of a braided river channel and channel bar, and intra-bar channels (chutes) may also develop in channel bar [42]. The intra-bar channel may widen into the main channel or be abandoned and filled with mud [26,43]. The fourth-order interface is usually a sedimentary discontinuity surface of the braided river channel or a contact surface between the braided channel and the channel bar. The third-order architecture unit is mainly the accretion body in the dam, and the third-order interface is mainly the interface between the accretion bodies, with lithologies consisting mostly of mudstone or siltstone.

(1) Braided channel

The braided channel is characterized by rapid flow, shallow water, fast lateral migration and low gravel content [4]. The lithology of the braided channel of the Lower Shihezi Formation in Jin 58 well area is mainly medium-fine sandstone, with occasional gravel deposits at the base of the sand body. As hydraulic energy decreases, siltstone or mudstone is deposited at the top of the sand body, forming a positive rhythm structure (Figure 3a). The electrical logging curve of the braided channels is bell-shaped, with a single sand body thickness of up to 6m, and parallel bedding and massive bedding are developed within the sand body.

(2) Channel bar

The channel bar is a common architecture unit in the braided river, mainly formed by sediment accumulation under the action of symmetric helical cross-flow [4]. The channel bar of the Lower Shihezi Formation in the study area is mainly composed of medium-coarse sandstone and gravelly sandstone, with trough cross-bedding and tabular cross-bedding developed. The sand bodies do not exhibit upward fining of grain size. The logging curve of a channel bar is box-shaped, and the thickness of a single channel bar can reach 8m, making it the best reservoir with excellent physical properties in the study area (Figure 3b).

(3) Overbank

Overbank deposits refer to fine-grained sediments carried by floods during the flood period, making it difficult to distinguish from the flood plain sediment [4,44]. In the Lower Shihezi Formation, overbank sedimentation is mainly composed of interbedded thin layers of siltstone and mudstone, with a finger-shaped logging curve (Figure 3c), and has poor physical properties, making it difficult to form good reservoirs.

(4) Flood plain

The flood plain is mainly distributed on both sides of the braided river channel and is formed by the suspension mass unloading of river water over the embankment away from the river channel [44]. The flood plain sedimentation in the study area is mainly composed of mudstone and muddy siltstone, with horizontal bedding and a relatively flat logging curve (Figure 3d).

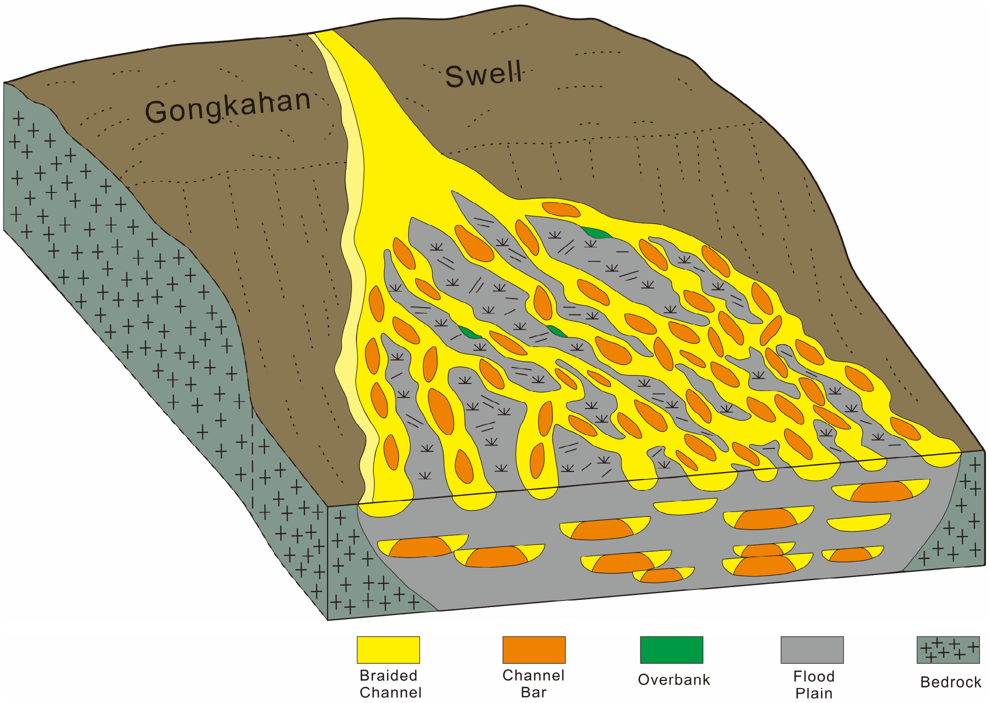


**Figure 2.** Braided river sedimentary model of Jin 58 well area.

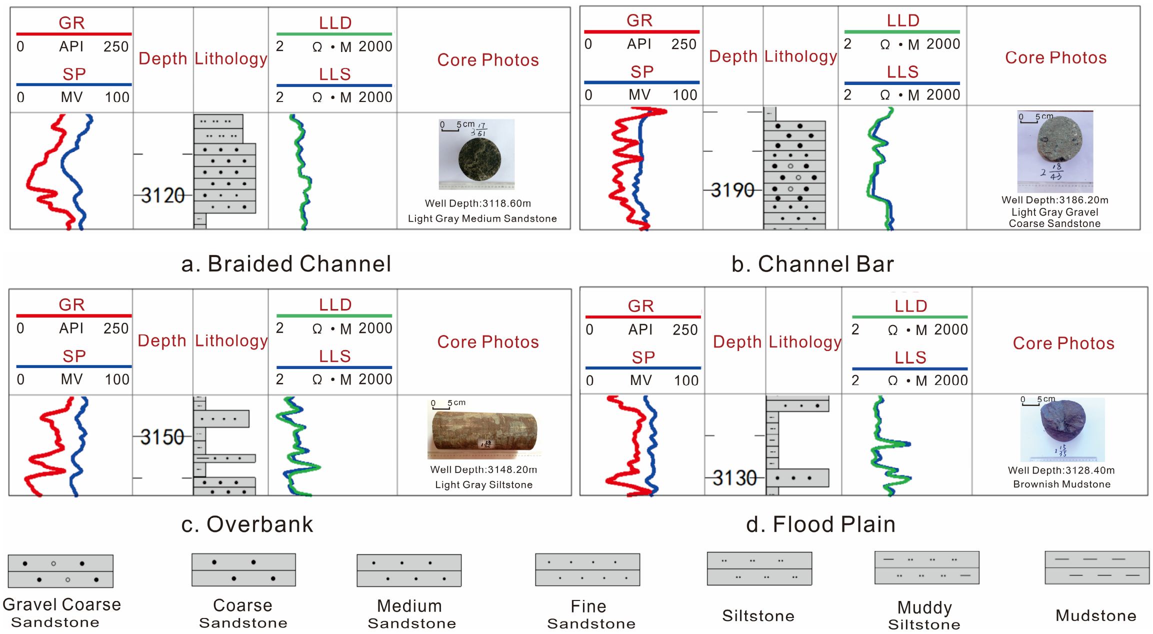


**Figure 3.** Braided river architecture unit in Jin58 well area.

### 4.2. Methods for Boundary Delineation of Single Sand Body Architecture

In the research of braided river reservoir development, it is particularly important to clarify the scale of channel sand body. Vertical well information has limitations, especially in areas with sparse well networks. Depending solely on vertical well information to characterize the interface of a single sand body architecture increases uncertainty in inter-well predictions, while horizontal wells provide abundant lateral information and greatly reduce inter-well uncertainty. Based on the identification of single well architecture, this study uses a combination of vertical and horizontal well information to delimit the reservoir architecture. Through the analysis of the architecture of the continuous well profile in the study area (Figure 4), it is believed that there are four identification markers for the boundary of a single sand body architecture in the Jin 58 well area; the horizontal section of the horizontal well encounters thick flood-plain mudstone, overbank deposition, elevation difference in the river channel, and thick-thin-thick characteristics of the river channel sand body.

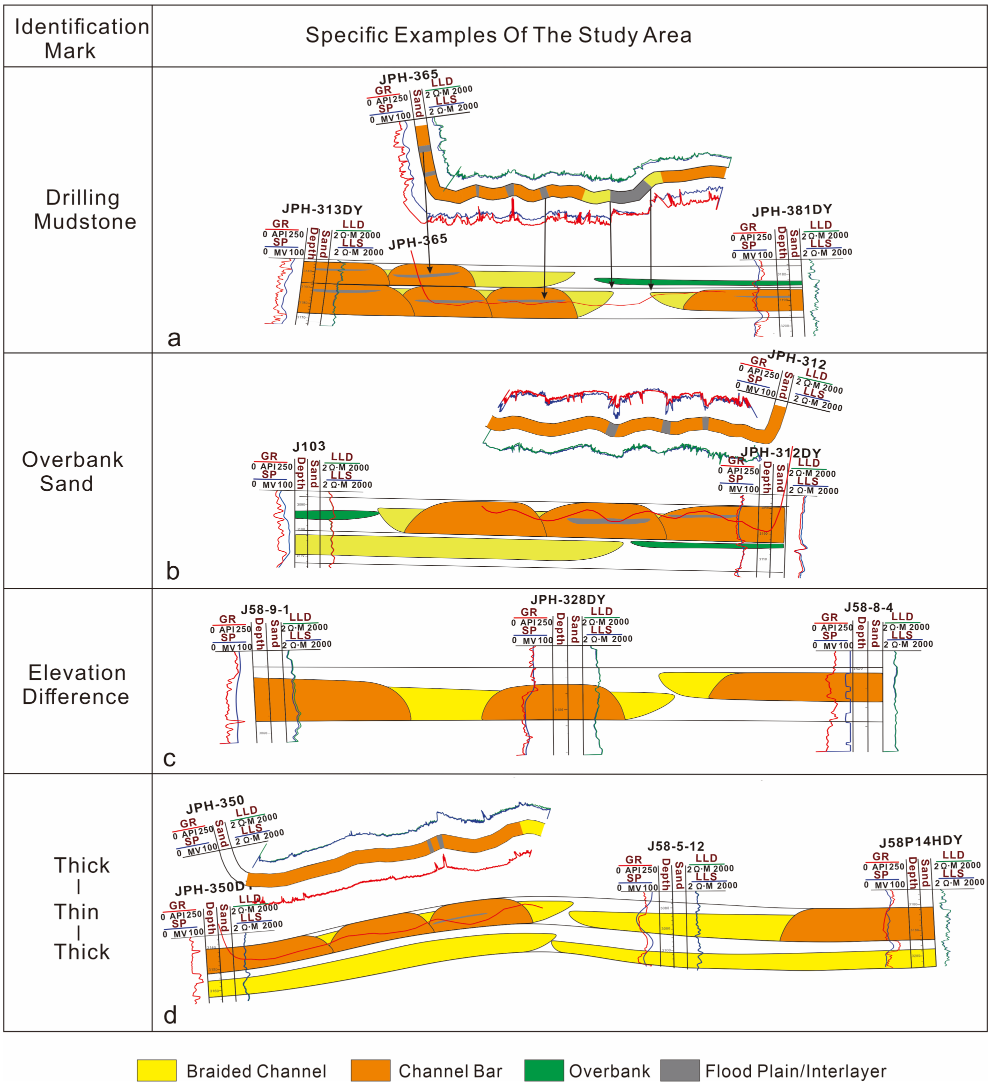


**Figure 4.** Four boundary identification signs of single sand body architecture based on well information. (**a**) Drilling Mudstone; (**b**) Overbank Sand; (**c**) Elevation Difference. (**d**) Thick-Thin-Thick.

(1) Horizontal well drilling flood plain mudstone: The horizontal direction of the horizontal well in the study area is approximately parallel to the direction of the river. Utilizing the rich lithological characteristics and logging information of the horizontal well, the sand and mud can be identified, and the location of the mudstone can be determined, which can lead to a more accurate identification of the boundary of the river channel sand body. Taking the continuous well profile of the first member of the box as an example (Figure 4a), the horizontal section of the horizontal well JPH-365 encountered a thick mudstone section, which divided the two channels. Based on this identification marker, the boundary of the river channel can be recognized in the horizontal section of the horizontal well, and by reasonable combination, the boundary of the river channel can be determined.

(2) Overbank deposition: The thickness of the overbank sand body is about 1–2 m, and its curve shape is finger-like (Figure 4b), which represents the edge of a single river channel. Therefore, the appearance of overbank sand body can be used as a marker to identify the boundary of a single river channel.

(3) Elevation differences of river channels: A single river channel has the form of "flat top and convex bottom" in the profile, and different periods of the river channel often have elevation differences (Figure 4c). Therefore, it is possible to judge whether two sand bodies belong to the same period of a river channel by comparing their heights. If there is a significant difference in elevation between the two, it indicates that they are formed by the superposition of sand bodies from different periods. However, this method is influenced by the results of stratigraphic correlation and needs to be combined with other identification markers for comprehensive judgment [45].

(4) Thick-Thin-Thick characteristics of the river sand body: The thickness of the river sand body formed in the same phase has the characteristics of being thick in the middle and thin on both sides. If two periods of river channels are laterally superimposed, the sand body thickness on the continuous well profile will show a combination of "thick-thin-thick" characteristics (Figure 4d).

### *4.3. Styles of Sand Body Architecture Superposition in Horizontal Wells*

#### 4.3.1. Prototype Model of Field Outcrop

In order to investigate the architecture and stacking patterns of the braided river deposits, we selected a sandstone braided river outcrop in Datong, Shanxi, which has similar sediment grain size and energy characteristics, for analysis (Figure 5). Within the outcrop profile, two primary fourth-order architectural elements can be identified, namely braided channel and channel bar. The braided channel and channel bar are stacked and spliced in different patterns both vertically and laterally, forming fifth-order architectural elements.

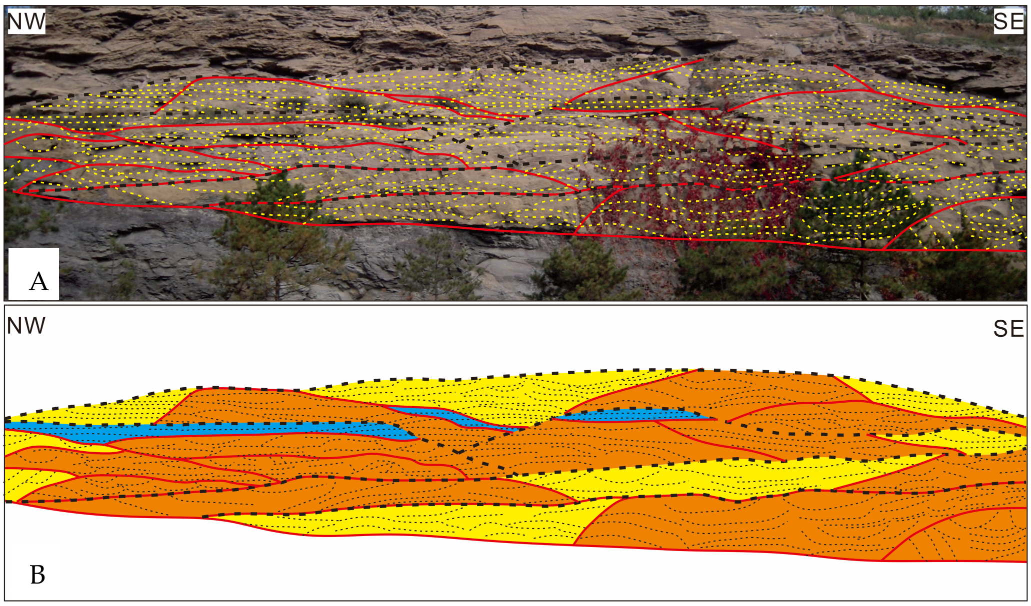


**Figure 5.** Outcrop section of Datong, Shanxi. (**A**) Outcrop photo; (**B**) Outcrop sketch

In the Datong field outcrop, it is observed that the channel bars are larger in scale than the braided channels. The braided channels exhibit a top-flat and bottom-convex shape, while the channel bars have a bottom-flat and top-convex shape, with extensive internal cross-bedding. The braided channels and channel bars are laterally spliced, forming composite sand bodies, although the interface between them is often not well-defined. The lateral splicing of the two architectural elements can be observed in two main styles: (1) The Channel bar–Channel bar stacking pattern is formed by downstream accretion, which has a large stacking area and presents an overall "bottom-flat and top-convex" shape. The lithology is primarily medium to coarse sandstone, and at the stacking interface, permeability barriers formed by fine-grained muddy deposits can be observed. (2) The Braided river–Channel bar stacking pattern, which exhibits a "bottom-flat and top-flat" shape in the profile, often shows braided channels cutting into the channel bars at the interface.

4.3.2. Vertical Combination Style

Due to the differences in sedimentary periods and sedimentary environments, sand bodies are superimposed and cut vertically during sedimentation, ultimately forming different combination styles in the vertical direction [46,47]. The identification of the stacking relationships of architecture units in the vertical direction essentially involves identifying architecture boundaries. In this study, two methods were used to delineate the architecture units vertically. The first method is through the identification of mud interlayers. These are mainly composed of mudstone and siltstone, resulting from fine-grained sedimentation between two periods of river channels due to lacustrine processes. The logging response characteristics of mud interlayers are high natural gamma-ray values and low resistivity. The second method is through electrical discontinuities. Due to differences in environmental conditions, flow rates, slope gradients, and sediment transport during the formation of different periods of river channels, there are variations in the grain size, physical properties, and sorting of the sandbodies. These variations are reflected as steps or abrupt changes in the resistivity curve. Based on well logging and core data, the sand bodies encountered in horizontal wells can be divided into two vertical combination styles, namely, the vertical multi-period braided channel–channel bar overlaid style and the vertical multi-period channel bar–channel bar overlaid style.

(1) Vertical multi-period braided channel–channel bar: It is manifested in the vertical direction as the superposition of the late-stage braided channel and the early-stage channel bar. Taking horizontal well JPH-326 as an example, the late-stage braided channel formed above the early-stage channel bar (Figure 6a), and the thickness of the braided channel is smaller than that of the bar. The channel bar is mainly composed of coarse-medium sandstone, with good sorting and a box-shaped logging curve, while the logging curve pattern of the braided channel exhibits a bell shape. Therefore, the logging curve in the vertical direction shows a superposition of bell-shaped and box-shaped patterns (Figure 6a).

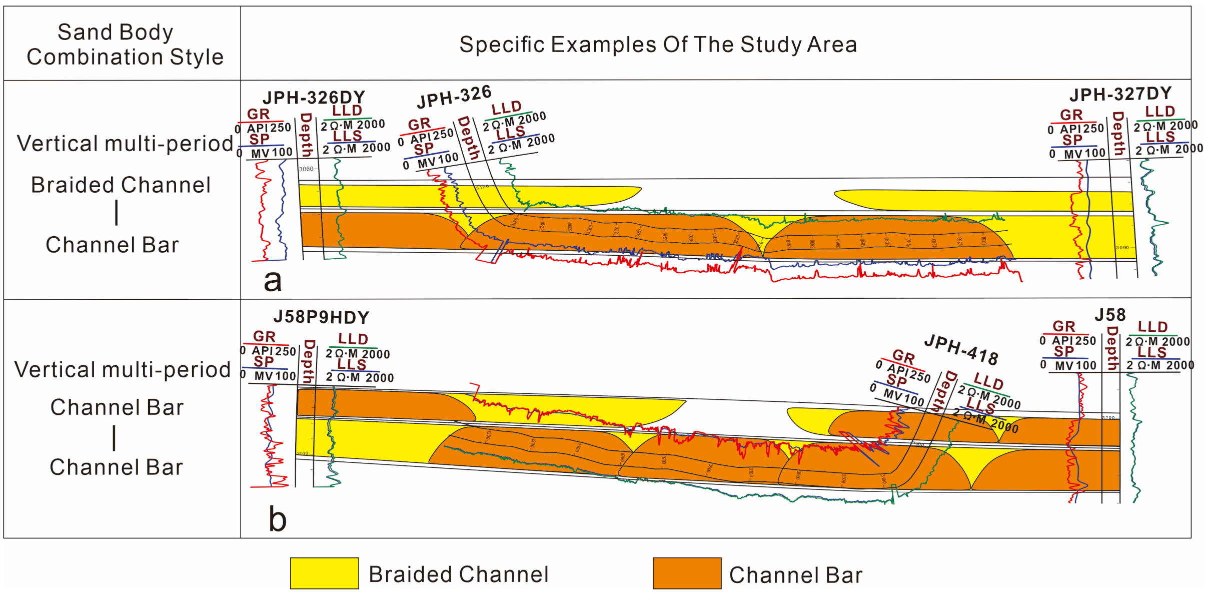


**Figure 6.** Vertical combination styles of architecture in study area. (**a**) Vertical multi–period braided channel–channel bar; (**b**) Vertical multi–period channel bar–channel bar

(2) Vertical multi-period channel bar–channel bar: It shows multi-period channel bar superposition in the vertical direction. The cause of this type of superposition relationship is that the late river scours the early river channel, resulting in the channel bar formed in the

late period superimposing on top of the channel bar formed in the early period (Figure 6b). Take horizontal well JPH-418 as an example; two stages of channel bar are developed in the vertical direction, which is shown as two box-shaped superposition on the logging curve. The two phases are superimposed in the vertical direction to form a composite channel bar, which is about 20 m thick and separated by a thin layer of mudstone.

The analysis of the vertical superposition style of the horizontal well architecture unit of the Jin 58 well area shows that the channel bar, as the main four-order architecture unit, can be superposed with the late channel bar and braided channel in the vertical direction, and its partitioning interface is mainly a lithological interface, which is mostly muddy siltstone or mudstone.

#### 4.3.3. Lateral Combination Style

The lateral combination style of the architecture units refers to the combination of the architecture units formed in the same period and the contact relationship [4], and there are mainly four lateral combination styles of the sand bodies drilled and encountered in the horizontal wells in the study area: isolated channel bar, multiple channel bar, and braided channel–channel bar type (Figure 7).

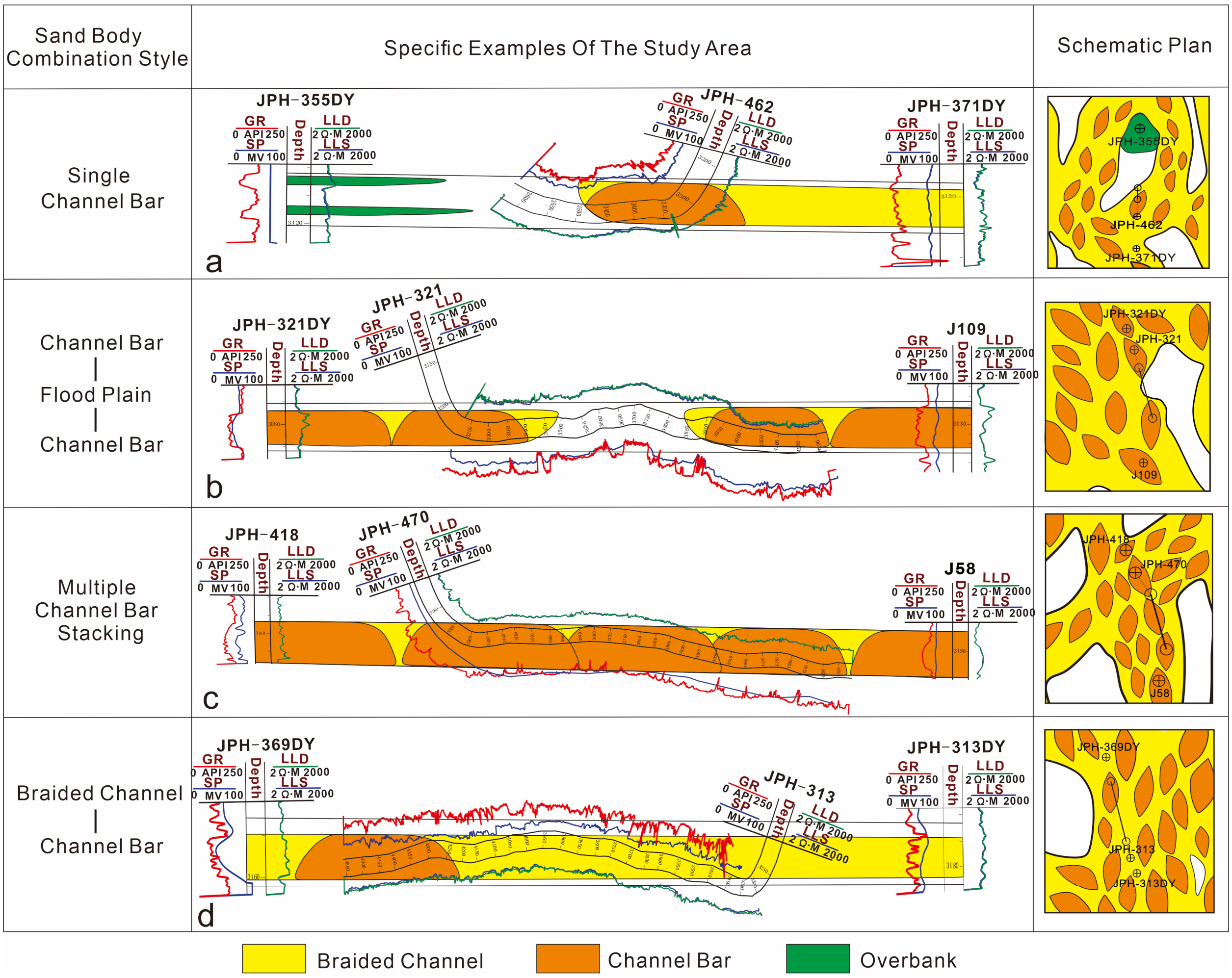


**Figure 7.** Lateral combination styles of architecture in study area. (**a**) Single channel bar; (**b**) Channel bar–flood plain–channel bar; (**c**) Multiple channel bar stacking; (**d**) Braided channel–channel bar.

(1) Isolated channel bar: the horizontal well encounters the discontinuous channel bar laterally, and the combination style of this type can be divided into a single channel bar and channel bar–interchannel–channel. Figure 7a shows a single channel bar encountered

in the horizontal section of well JPH-362, with a box-shaped logging curve and good reservoir properties, and it is laterally spliced with interchannel mud. Figure 7b shows two isolated channel bars encountered in the horizontal section of well JPH-321, with box-shaped log curves and good reservoir properties, and about 8m thick vertically. The two channel bars are separated by a large section of mudstone, which causes the sand bodies of the two periods of channels not to contact each other, with no cutting relationship between them.

(2) Multiple channel bar stacking: the horizontal well encounters multiple continuous channel bars laterally, exhibiting a cutting contact relationship, which is a more common type of lateral splicing style in the study area. Taking well JPH-470 as an example, under the action of progradation, multiple channel bars are superimposed downstream to form a composite channel bar (Figure 7c), with box-shaped logging curves, little lithological variation, strong sand body connectivity, excellent reservoir properties, and high production.

(3) Braided channel-channel bar: The horizontal well encounters braided channel and channel bar successively in the lateral direction. Take horizontal well JPH-313 as an example; sediment carried by the water flow is deposited in the middle of the braided riverbed, forming a channel bar with a box-shaped logging curve and coarse sediment particles. Braided channel deposits are formed on both sides of the channel bars, with a bell-shaped logging curve and thin sandstone thickness (Figure 7d). The production of this type is generally lower than that of a multiple channel bar.

### *4.4. Internal Architecture Characteristics of Channel Bars*

The channel bar is widely developed in braided rivers, with complex internal structures and strong heterogeneity, corresponding to the fourth-level architecture unit in Miall's [41] classification scheme, and is the focus of research on sandy gravel braided rivers. Scholars at home and abroad have conducted extensive research on the identification of the single channel bar. This study focuses on an anatomical analysis of the internal architecture of the channel bar.

#### 4.4.1. Internal Architecture Patterns of Channel Bar

A channel bar can be vertically divided into the vertical body, the vertical surface, and the silting layer [48], and horizontally divided into bar head, bar tail, main body, and limb, with a different development degree and dip angle of the silting layer in each part. The bar head is located on the upstream side of the channel bar, and the interlayer formed in the early stage is difficult to preserve under the continuous scouring of the water flow. The bar tail is located on the downstream side of the channel bar, and is mainly subjected to progradation under the action of water flow, with a high degree of preservation of the interlayer. In the geological context of the research area, the architecture pattern and internal characteristics of the channel bar are influenced by river water flow. When the river water flow is high and energy is strong, the water overflows the channel bar, resulting in the superposition of multiple periods of progradation bodies to form the channel bar. When the river water flow is low and energy is weak, the water level is lower than the channel bar, and lateral accretion bodies form on both sides of the channel bar. In addition, climate conditions are also an important influencing factor. When the climate is humid and precipitation is strong, the river water flow will become stronger, thereby affecting the architecture pattern of the channel bar. Especially during flood periods, the river water overflows the channel bar, resulting in vertical aggradation.

In this paper, using the abundant information of horizontal wells in the study area and combining the previous research results on braided river architecture [26,27], we established a suitable channel bar architecture model for the study area, that is, the accretion body within the channel bar has the depositional characteristics of gentle progradation in the downstream direction (Figure 8c), and the pattern of vertical accretion is mostly developed in the vertical flow direction (Figure 8b). The interface of the main part of the heart beach is nearly horizontal, with a steeper beach head and a gentler beach tail, and has the characteristics of downstream accretion [49]. The tertiary interface between different accretionary bodies is formed by different contemporaneous floods, and the silting layer is mainly distributed between the interfaces of different accretionary bodies in a draped pattern.

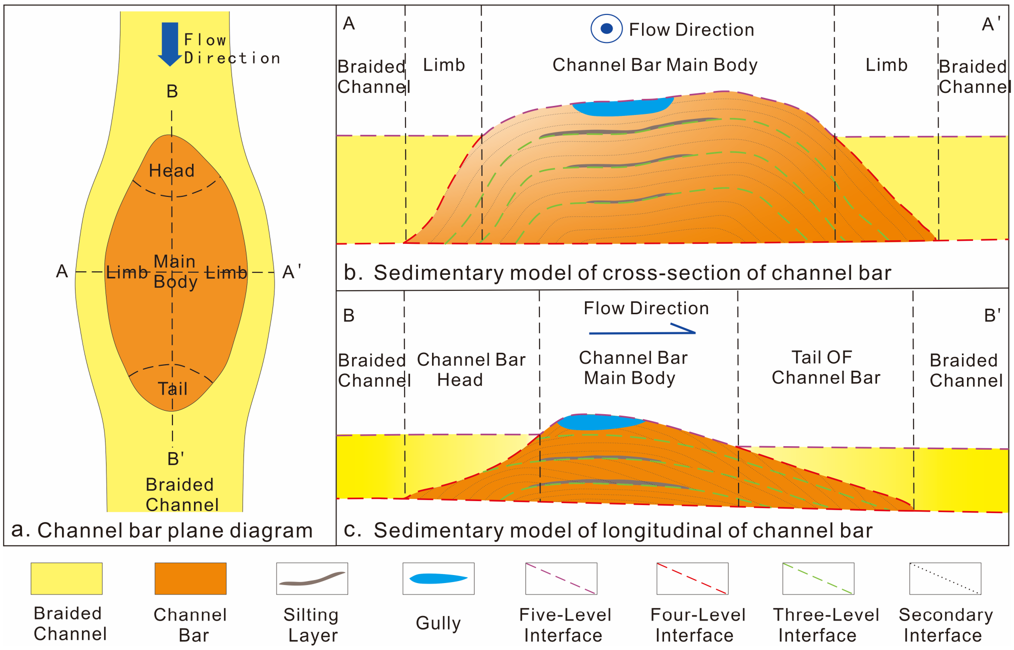


**Figure 8.** Braided river architecture mode and architecture interface.

4.4.2. Types and Characteristics of Interlayer in the Channel Bar

According to the sedimentary genesis, the interlayer inside the channel bar of the study area can be divided into three categories: muddy silting layer, physical silting layer, and muddy interlayer caused by gully. The lithology of the muddy silting layer is mainly composed of mudstone and mud-siltstone, which is developed between accretionary body interfaces, with thin thickness and high gamma value and low resistivity value on the logging curve. The lithology of the physical silting layer is coarser, with a high gamma ray value and a lower resistivity value. The muddy interlayer caused by gully is mostly developed at the top of the channel bar, with a thicker thickness and a higher gamma ray value, but lower porosity and permeability values (Figure 9a).

For the three-level architecture unit, the abundant lateral information of horizontal wells provides a reliable basis for the architecture characterization. Taking horizontal well JPH-326 as an example, the horizontal section of the well was drilled in the H1-3-2 layer. According to the characteristics of the logging curve and the previous studies on the scale of the channel bar [26,27], it can be judged that three channel bars were drilled in the horizontal section of the well successively, two gullies were developed at the top of the channel bar, and two silting layers can be identified in the channel bar 1 (Figure 9b). Based on the thickness range of the accretion body determined by the coring well and the characteristics of the downstream accretion of the channel bar, it can be determined that three stages of accretion are developed in channel bar 1, and the silting layer is draped between the interface of the accretion body. The dip angle of the silting layer can be calculated using the formula (Figure 9c), and the results show that the silting layer in the center part of the channel bar is approximately horizontal, and the dip angle of the silting layer in the limb of the channel bar is larger than that in the tail part, mainly because the water body energy in the tail part is weaker and the scouring effect is weaker.

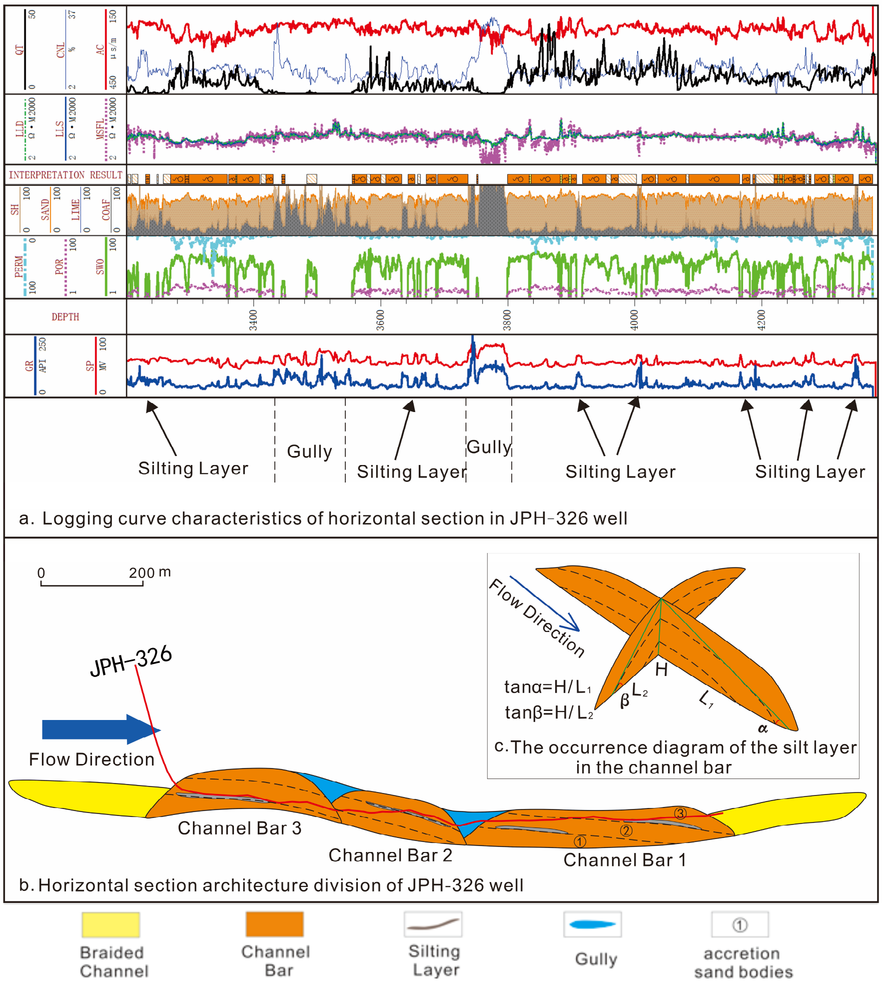


**Figure 9.** Characteristics of interlayers drilled in horizontal section of well JPH-326.

## *4.5. Embedded 3D Hierarchical Architecture Modeling*

Reservoir architecture modeling is one way to characterize the spatial variation of reservoir heterogeneity and other features, which can accurately characterize the architecture interface. At present, the main methods for reservoir architecture modeling include sequential indicator simulation, truncated Gaussian simulation, multipoint geostatistical simulation, etc. [6], but these methods encounter varying degrees of difficulties in quantitatively modeling architecture [2]. This architecture modeling is mainly based on the previous fine research on the architecture and the division results of different levels of reservoir architecture interfaces. The embedded hierarchical modeling is used to establish the three-dimensional architecture model of the reservoir in the study area.

### 4.5.1. Five-Level Architecture Unit Distribution Model

Based on the identification results of a single channel, the top and bottom interfaces are determined, and the architecture unit within the two interfaces is the single channel, while the floodplain is located between the single channel unit. When the channel is cut and stacked, the top interface of the early channel overlaps with the bottom interface of the later channel to reflect the cutting and superposition of the channels, and ultimately, a five-level architecture unit distribution model is established under the control of the top and bottom interfaces.

Taking the single channel in H1-3 as an example (Figure 10a), 16 isolated single channels were distributed, and the top and bottom interfaces of these channels were delineated in the well-log section, with a total of 32 layers delineated to construct the external morphology of the single channel. According to the top and bottom layering of the single channel and its contact relationships with other channels, a three-dimensional model of the 16 single channels is established (Figure 10b).

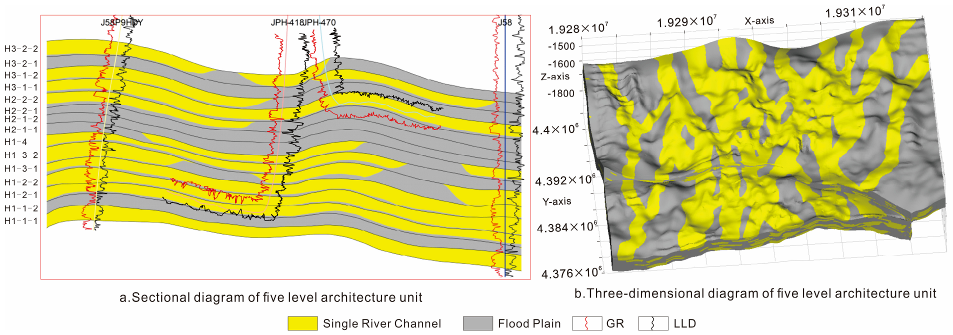


**Figure 10.** Distribution pattern of single channel and flood plain in Jin 58 well area.

### 4.5.2. Four-Level Architecture Unit Distribution Model

Compared with sedimentary microfacies modeling, the principles followed in architecture modeling are basically the same, but architecture modeling at the single microfacies level is more refined as it reflects the spatial stacking relationships of the sand body and better characterizes the distribution patterns of the sand body.

As the top-bottom of a single river channel has been defined, establishing a four-level architecture unit model within a single river channel only needs to combine the division results of the architecture interface and the combination style of the braided channel and the channel bar to determine the top and bottom interface, combination characteristics, and sedimentary periods of the braided channel and the heart beach (Figures 11 and 12).

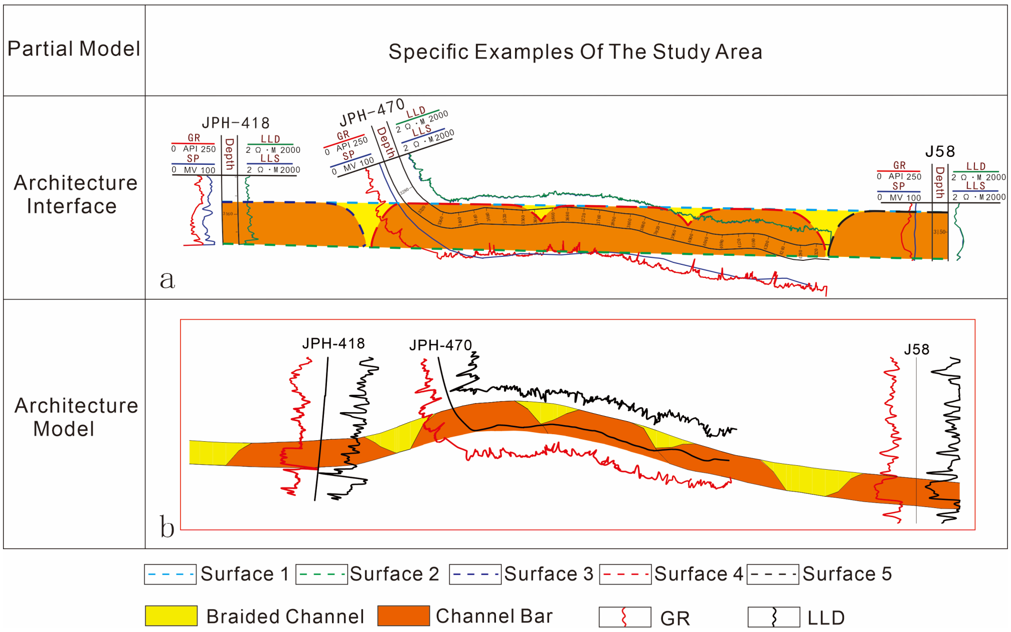


**Figure 11.** The period and model profile of architecture unit in layer H3-1-1. (**a**) Architecture Interface; (**b**) Architecture Model.

Taking the H3-1-1 layer as an example (Figure 11a), based on the results of the architecture study, the combined style of the braided channel and channel bar has been clearly defined: a braided channel and five channel bars are developed in a single river, three channel bars in the middle overlap each other, and the channel bars on both sides are isolated. Layer 1 and layer 2 represent the top and bottom interfaces of the braided channel, respectively, while layer 3 and layer 2 represent the top and bottom interfaces of channel bar 1, and layer 4 and layer 2 represent the top and bottom interfaces of channel bars 2, 3, and 4. Layer 5 and layer 2 represent the top and bottom interfaces of channel bar 5. Based on the layered interfaces and the stacking relationships between the architectures (Figure 11a), the distribution model of the braided channel and channel bars controlled by the interfaces has been determined (Figure 11b).

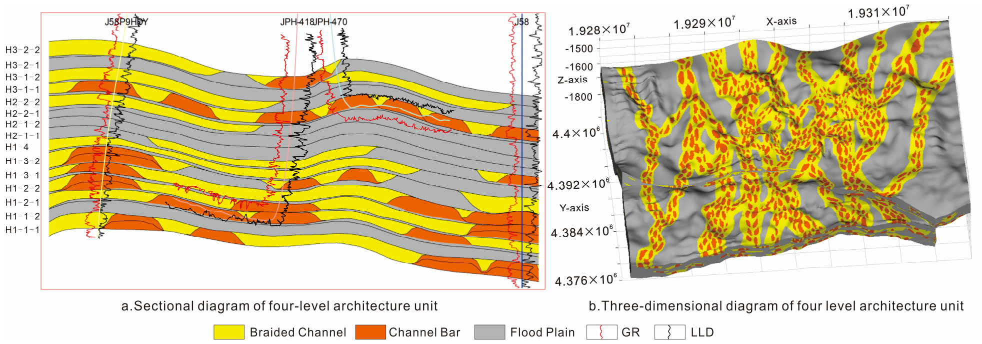


**Figure 12.** The four-level architecture unit model of Jin 58 well area.

### *4.6. Significance of Oil and Gas Development*

The frequent channel avulsion of braided rivers in the Lower Shihetanzi Formation in the J58 well area has made the fine characterization of reservoirs a challenge in the gas field development process. The stacking relationship and pattern of sand bodies constrain the drilling encounter rate and connectivity of the sand bodies, thus the detailed characterization of reservoir architecture plays an important guiding role in gas field development and production. Research has shown that the stacking patterns of sand bodies in the J58 well area are closely related to productivity. The sand bodies in the Box 3 and Box 2 intervals are mainly vertically isolated and laterally isolated, resulting in poor productivity (Figure 13). In contrast, the sand bodies in the Box 1 interval are well-developed, with multiple channel incisions and less retention of mud deposits. The channel bars in the channels are well-developed, resulting in higher drilling encounter rates. The sand bodies exhibit a composite and laterally spliced pattern, indicating better connectivity and higher productivity (Figure 13). Overall, the composite and laterally spliced sand bodies in the Box 1 interval of the J58 well area are high-quality reservoirs and represent a promising area for further development.

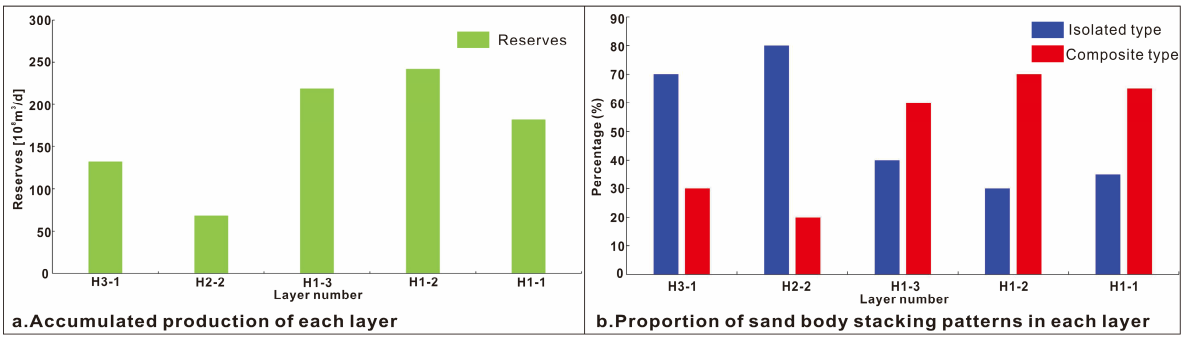


**Figure 13.** Relationship between stacking patterns of sand bodies in different layers and productivity changes in Jin 58 well area of Ordos Basin.

In addition, based on detailed architecture analysis, numerical simulation with a fitting rate of 85% (Figure 14a) has been conducted, which validates the accuracy of the architecture analysis. The numerical simulation results indicate that the inter-well displacement distance L is proportional to the square root of time, i.e., $L = 39\sqrt{t}$ (Figure 14b). Based on this conclusion, it provides a basis and guidance for the later well deployment (Figure 14c).

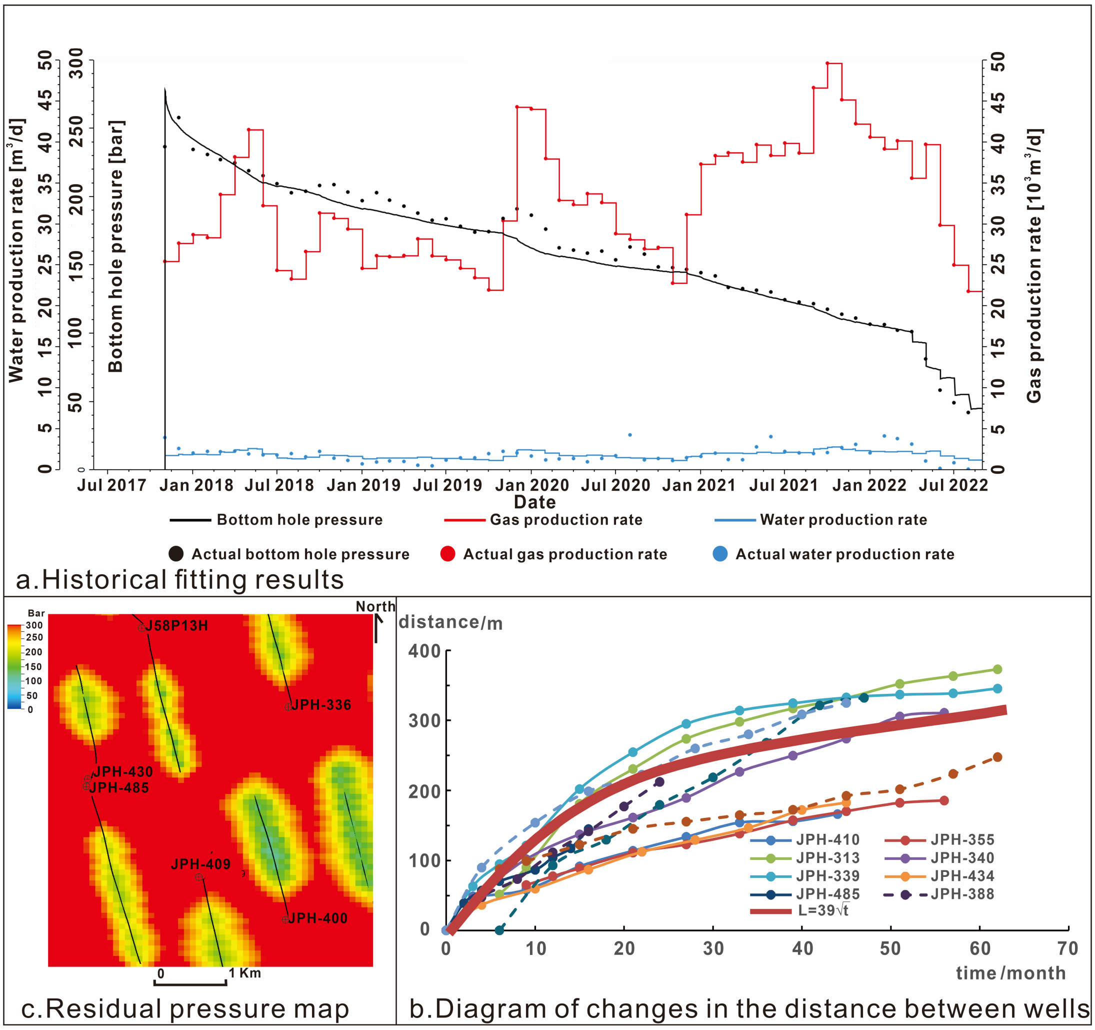


**Figure 14.** Numerical simulation results.

## 5. Discussion

Currently, research on braided rivers is still in the exploratory stage. Although many scholars have conducted extensive work on the description of underground reservoirs based on core samples, field outcrops, and laboratory experiments, there are still many questions worthy of consideration. Firstly, the characterization of the development positions of channel bars in braided river reservoirs is highly speculative, and there is significant uncertainty in predicting the scale of internal avulsion layers and aggradational bodies. Secondly, the scale of braided river channels and channel bars formed in different sedimentary environments varies, and there are significant differences in the empirical formulas used by previous researchers to predict reservoir architectures. Therefore, these formulas may not be applicable until the sedimentary environment of the braided river is clearly defined. Thirdly, braided rivers have poor stability and are prone to modification, so it is worth considering whether it is appropriate to base the study of underground reservoir architectures on parameters derived from modern braided rivers. Lastly, the modeling of braided river reservoir architectures is still in its early stages, and the complexity of braided river reservoirs increases the uncertainty in modeling, especially in accurately simulating internal interbeds.

Applying multiple methods and interdisciplinary approaches to dissect the reservoir architecture of braided rivers is a future trend in architecture characterization. Further research may be needed in the following areas: (1) Enhancing the analysis of braided rivers in various sedimentary types, establishing architecture models, parameters, and splicing styles for braided river reservoirs in different sedimentary environments; (2) Combining multiple methods such as ground-penetrating radar, geophysical logging, seismic techniques, field outcrops, and core analysis to establish a knowledge base for the architecture of braided river reservoirs; and (3) Strengthening flume experiments to study the development positions of channel bars, architecture splicing styles, and architecture parameters.

## 6. Conclusions

(1) Braided river deposits are developed in the Jin 58 well area, and the reservoir sand bodies are mainly composed of the channel bar and braided channel. Based on the data from horizontal and vertical wells, the identification criteria for a single sand body have been determined, which include inter-channel mud, overbank sand body, elevation differences within channels, and the existence of the thick-thin-thick feature of the river sand body. This provides a foundation for reservoir architecture analysis.

(2) According to the sand body distribution encountered by horizontal wells, two vertical stacking patterns of braided channel–channel bar and channel bar–channel bar architectures have been established, as well as four lateral splicing patterns of single channel bar, channel bar–braided channel–channel bar, multiple channel bars, and braided channel–channel bar architectures. The stacking patterns of sand bodies are closely related to production, among which multi-stage stacking sand bodies have good gas content and high reserves, making them a promising type for development.

(3) Based on the identification of architecture units from individual wells and the study of their stacking relationships, a 3D architecture model has been established using an embedded modeling method, which clearly displays the distribution of the braided channel and channel bar under hierarchical constraints. This model provides geological evidence for optimizing the development plan.

(4) Based on the established architecture model, numerical simulations were conducted, and the fitting rate reached 85%. This not only verified the accuracy of the model but also clarified the relationship between the distance of the well interference and time, providing a basis for subsequent well deployment.

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