Reservoir architecture patterns of sandy gravel braided distributary channel
A case study of Triassic Upper Karamay Formation, Xinjiang oilfield

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ABSTRACT

The purpose of this study was to discuss shape, scale and superimposed types of sandy gravel bodies in sandy-gravel braided distributary channel. Lithofacies analysis, hierarchy bounding surface analysis and subsurface dense well pattern combining with outcrops method were used to examine reservoir architecture patterns of sandy gravel braided distributary channel based on cores, well logging, and outcrops data, and the reservoir architecture patterns of sandy gravel braided distributary channels in different grades have been established. The study shows: (1) The main reservoir architecture elements for sandy gravel braided channel delta are distributary channel and overbank sand, while reservoir flow barrier elements are interchannel and lacustrine mudstone. (2) The compound sand bodies in the sandy gravel braided delta distributary channel take on three shapes: sheet-like distributary channel sand body, interweave strip distributary channel sand body, single strip distributary channel sand body. (3) Identification marks of single distributary channel include: elevation of sand body top, lateral overlaying, "thick-thin-thick" feature of sand bodies, interchannel mudstone and overbank sand between distributary channels and the differences in well log curve shape of sand bodies. (4) Nine lithofacies types were distinguished in distributary channel unit interior, different channel units have different lithofacies association sequence.

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1. Introduction

Deltas are prominent triangle-like depositional bodies with discontinuous shoreline formed in relatively static and stable catchment basins or areas by large amounts of sediments carried by rivers [1]. Sedimentologists have paid great attention on deltas because of their complicated sedimentary origins, substantial oil and gas reserves and high reservoir quality. Consequently, they are the focus and hotspot of the oil and gas field exploration and development [2–11]. A lot of understandings on sedimentary sequence, lithofacies association, architecture elements and sedimentary architecture mode of gravel braided deltas have been obtained [12–22], in particular, major progresses have been made in the study on dip angle, scale and distribution pattern of intercalations in mouth bars of sandy braided rivers [23–31]. However, more researches need to be done on vertical...
depositional sequence, lithofacies association, architecture elements and sedimentary architecture mode of the gravel braided river deltas close to the provenance and coarse in grain size. In particular, the study on typical architecture elements of braided river delta front, such as the scale, distribution pattern and superimposed relationship of intercalations in mouth bars, and their controlling effect on the distribution of remaining oil, is still inadequate.

There are 597 wells including producing wells and passing wells in the study area, at an average well space of approximate 140 m, and about 80 m in local areas, providing abundant core well logging, outcrop, dynamic production, and test data. The basic method of this research is to use outcrop, core and well logging data research and analyses of the architectural element morphologies, scale, and overlaying styles of the sandy gravel braided distributary channel. There are abundant data including outcrop and underground wells. In the northwestern study region, there are 13 outcrop datasets with good exposure in the Triassic Upper Karamay Formation, which can identify lithofacies and depositional architecture elements of the sandy gravel braided distributary channel. There is are approximately 140 m between wells or 80 m where there is dense coverage. Cored wells are used to identify the lithofacies and vertical ranges of architecture units and to calibrate the data of non-core wells.

2. Geological setting

About 12 km east of downtown Karamay, Block Yizhong of Karamay oilfield is a faulted block oilfield bordered with 1st West zone to the southwest, 1st East zone to the northeast, the fracture of Black Oil Hill to the northwest and fracture of Karamay-Urho to the southeast (Fig. 1). There develop Carboniferous, Middle Triassic Lower Karamay Formation (T2k1), Upper Karamay Formation (T3k2), Upper Triassic Baijiantan Formation (T3b), Lower Jurassic Badaowan Formation, Sangonghe Formation, Middle Jurassic Xishanyao Formation, Toudunhe Formation, Upper Jurassic Qigu Formation, Lower Cretaceous Tugulu Formation from bottom to top. Among them, Upper Karamay Formation with an average thickness of 30 m–50 m, can be divided into 5 sand groups from bottom to top: S5, S4, S3, S2, S1 [32]. The reservoir of Upper Karamay Formation belongs to braided river delta system (S5, S4) and braided river sedimentary system (S3, S2, S1), featuring coarse grain size and medium-good sorting. Its lithology is mainly dark gray, grayish-green mudstone and silty mudstone and gray white coarse sandstone, sandy conglomerate and medium-fine sandstone; the sands in the upper part are thicker, and dominated by grayish green sandstone and conglomerate, gray mudstone and silty mudstone. The targets S5, S4 in the study area are braided river delta reservoirs [5,33,34], mainly distributary channels in the work area, with thickness of single sand body of 1.5 m–1.7 m. The sand bodies are poor in continuity and strong in heterogeneity. The data of core analysis shows the cores have an average porosity of around 18.9%, and average permeability of about 140 × 10⁻³ μm², representing medium porosity and medium-low permeability.

3. Architecture elements of sandy gravel braided distributary channels and its hierarchical division.

3.1. Architecture elements of sandy gravel braided distributary channels

Different sedimentary origins lead to different sedimentary architecture elements. The identification and definition of architecture elements are the basis for the study of the area (Fig. 2).

(1) Distributary channel
① Lithology features: the main lithofacies association is composed of massive bedding fine conglomerate lithofacies, large-scale trough cross bedding sandy conglomerate lithofacies at the bottom and trough cross bedding coarse sandstone lithofacies, planar bedding medium- fine sand lithofacies and massive silty mudstone and massive mudstone lithofacies from bottom up. The grain size shows positive rhythm of fining upward vertically, the product of strong hydrodynamic condition (Fig. 3B, C, F).
② Features of sedimentary structure: trough cross bedding, planar cross bedding, wavy cross bedding and parallel bedding are commonly seen, which are the characteristics of traction current. Apparent scour surfaces are common in the bottom and argillaceous conglomerate is seen in local parts of the bottom.
③ Characteristics of logging response: box, bell or slightly serrated bell shapes on SP, GR, Rt, and AC logging curves. All the top of box shape curves show abrupt contact; while the bell shape curves take on abrupt contact at bottom and gradual contact at top.

![Fig. 1. Location and stratigraphic sequence of the work area.](image-url)
Overbank sand is formed during floods by fine sandy sediments overflowing the bank of distributary rivers.

1. Lithology features: dominated by grey siltstone, grey medium-fine sandstone and grey-white coarse sandstone, with laminated siltstone and argillaceous siltstone. The sandstone thickness is thin with finning upward positive rhythm or had no significant changes (Fig. 3F).
2. Features of sedimentary structures: there develop massive bedding, horizontal bedding, wavy bedding, lenticular bedding and flaser bedding.
3. Characteristic of logging response: show serrated-bell shape, finger shape on SP, GR, Rt, AC curves. The sands are very thin.

Interchannel mudstone:
1. Lithologic features: dominated by siltstone, argillaceous siltstone and mudstone with carbon dust. The mudstone is deep grey, greyish black or greyish green, indicating the sedimentary environment is weak redox environment (Fig. 3A, D).
2. Features of sedimentary structures: massive bedding, horizontal bedding, lenticular bedding and carbonizing fossil plant stem are commonly seen, suggesting weak flow and still swamp sedimentary environment.
3. Characteristic of logging response: The typical logging response of interchannel mudstone is SP at the base line of mudstone, and almost unchanging Rt.

A-Gray mudstone and siltstone interbed, wave bedding, including plant roots fossil, 660.26 m, S51-1, T10193; B-Gray conglomerate sandstone inrush of oil, 663.82 m, S51-2, T10193; Fine sandstone inrush of oil and mudstone, 664.47 m, S52-1, T10193; D-Gray fine sandstone containing carbon, 666.09 m, S52-1, T10193; E-gravel sandstone, 665.33 m, S51-2, T10193; F-Mudstone interbedded with siltstone, 861.9 m, S42, T10241.

3.2. Hierarchy of gravel braided distributary channels.

Consulting the division of [35] and in line with the actual conditions of the section, the distributary channels of gravel braided delta were divided into several structure levels (Table 1).

4. Architecture of gravel braided distributary channels

On the basis of stratigraphic correlation and identification of sedimentary facies, and under the direction of the ideology of model fitting, hierarchy analysis [36,37], the reservoir architecture of sandy braided distributary channels is characterized. The gravel braided distributary channels are dissected in three levels, compound distributary channel, single channel belt and distributary channel.

4.1. Characteristics of distributary channel complex

4.1.1. Method
First of all, the distributary channel complexes in the studied area were dissected. According to the description of core, logging curves were calibrated with core data to find out the logging facies plate of various architecture elements, on this basis, architecture elements of all single wells in the study area were interpreted, and then architecture element interpolation was done by means of indicator Kriging to get a draft of sand complex
distribution, then the sand complexes were reprocessed by using human–computer interaction. The thickness contour map of sandy conglomerate was made by using the thickness of sandy conglomerate extracted from single wells to make thickness pre-analysis.

Based on the distribution of sandy conglomerate thickness, and logging facies of each single well, the planar distribution of sedimentary facies was worked out, and then under the guidance of depositional model, the reasonable sand complex distribution was fitted, finally the planar distribution pattern and vertical evolution regularity of the sand complexes were analyzed.

4.1.2. Distribution pattern

Under the guidance of the research thinking mentioned above, distribution pattern of distributary channel sand complexes in 6 single layers of S4 and S5 sand groups of Upper Karamay Formation were examined. The comprehensive analysis shows the sand complexes in the study area appear in three distribution patterns: sheet, intertwined strips and single strip (Fig. 4).

(1) Sheet distributary channel sands

In the east of the study area, the distributary channel sand complexes are continuous in distribution in the plane with a width of more than 1500 m, as the overbank sands and inter-channel mudstone aren’t developed. The sheet distributary channel sands are the result of sufficient provenance supply and small accommodation, which reflects that frequent channel shifting makes it difficult for overbank sand and interchannel mudstone to preserve, so distributary channel sands of different period join together laterally in the same layer, forming sheet-like distributary channel sand complexes in big pieces (Fig. 4, S5\text{1}/C0\text{1}, S5\text{2}/C0\text{2}).

(2) Distributary channel sands in intertwined strip shape

In the plane, distributary channels distribute like interweaving belts, and mudstone often develops between the distributary channels, while overbank sands often occur at the margin of distributary channels or on the interchannel mudstone sporadically. Consequently, the distributary channel sands in strip shape are poor in lateral continuity and intertwine with each other. Interweaving strip-like distributary channel sands are the product when the rate of sedimentary supply is greater than the rate of accommodation increase. The channel shift in lateral direction gives rise to the joining of distributary channel sand of different period in the same layer, forming channel sand complexes continuous in the plane (Fig. 4, S5\text{1}/C0\text{1}, S5\text{2}/C0\text{2}).

(3) Single strip distributary channel sands

In single strip shape, this kind of distributary channel sands appear on the background of interchannel mudstone, with overbank sand developing at their margin or on the interchannel mudstone sporadically, therefore, they are poorest in the lateral continuity. This kind of sands comes about at insufficient provenance supply, big accommodation and weak shifting ability of channels (Fig. 4, S4, S5\text{2}).
4.2. Characteristics of single distributary channel belt

4.2.1. Boundary recognition of single micro-facies sand complexes

The key to distinguish single micro-facies sand complexes is to find out recognition marks of their boundary. The following recognition marks have been identified based on origin identification of sands in single wells and reasonable combination of single micro-facies complexes on section:

① Recognition marks of single distributary channel

In this study, it is the single distributary channel belts in distributary channel sand complexes that need to be recognized. It is must be noted that the single distributary channel belts in this paper are the distributary channel sand complexes distinguishable under the present well space.

The key to distinguish single distributary channels is to recognize the boundary of the channels correctly. It is found from the study on planar distribution features of single layer sedimentary micro-facies that single distributary channels in a single layer distribute in two patterns, assemblage of distributary channels of different periods in the same layer, and assemblage of distributary channels of the same period in the same layer. Hence, 5 recognition marks of single distributary channel belt boundary have been picked up (Fig. 5).

A Top surface depth displacement of distributary channel sands.

In the same time period, distributary channel sands of different stages can be developed successively. Different in deposition time, distributary channel sands of different stages are different in relative distance from their top surface to the marker bed (or formation boundary), in other words, there are differences in relative elevation of their top surface. Therefore, relative elevation of distributary channel top surface is a recognition mark to recognize single distributary channel boundary.

B Lateral superposition of distributary channel sands.

In the same time period (a single layer), the channel formed later often cut the channel formed earlier laterally in a fairly big range, and the channels of two stages are in abrupt contact at the joint place. These characteristics are considered marks of lateral superposition of channels of two stages.

C Feature of “thick-thin-thick” of distributary channel sands.

In section, if the thickness of distributary channel sands has the feature of “thick-thin-thick”, there must be single distributary channel boundaries. In the same time period, the channel formed later cut the channel formed earlier laterally, so the thin part in the middle of the sand is the margin of a channel sand.

D Interchannel mudstone or overbank sand between distributary channels.

The appearance of interchannel mudstone between distributary channels marks the end of a single channel. Overbank sand often occurs at the edge of distributary channel sands or in low spots in interchannel, relatively small in thickness and poor in physical properties.

E Differences of distributary channel sands on logging curves.

Formed in different hydrodynamic conditions, different distributary channel sands are different in logging response, for example the differences in shape and amplitude on SP curve and 0.25 m electrical resistivity curve, these differences can be taken as the assistant marks to distinguish single distributary channels.

A. Top surface depth displacement of different distributary channel sands; B. Lateral superposition of distributary channel sands of two stages; C. Feature of “thick-thin-thick” of distributary channel sand; D. Interchannel mudstone or overbank sand appearing between different distributary channels; E. Differences of different distributary channel sands on logging curves.
4.2.2. Distribution features of single distributary channel

Under the direction of recognition marks of single microfacies, single distributary channels of single layers were identified according to the 5 recognition marks. The results show that single distributary channels distribute in strip and branch shape in the plane, with a width of 100 m–450 m (Table 2).

According to architecture boundary identification marks, the objective single layer was analyzed by more-refined architecture in the studied area. For example of S51/C0, in northwestern of the study area suffered by erosion. Distributary channel sand body is mixed a belt shape distribution. Multiple single channels superimposed with migration pattern. There are 4 single

Table 2

<table>
<thead>
<tr>
<th>Formation</th>
<th>Geometry characteristic</th>
<th>Lateral scale(m)</th>
<th>Thickness (m)</th>
</tr>
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<tr>
<td>S41</td>
<td>single strip</td>
<td>100–130</td>
<td>1.5–5</td>
</tr>
<tr>
<td>S42</td>
<td>interweaving strip</td>
<td>110–400</td>
<td>1.5–7.6</td>
</tr>
<tr>
<td>S51</td>
<td>interweaving strip</td>
<td>100–400</td>
<td>1.5–6.6</td>
</tr>
<tr>
<td>S52</td>
<td>interweaving strip</td>
<td>100–350</td>
<td>1.5–7.4</td>
</tr>
<tr>
<td>S53</td>
<td>sheet</td>
<td>110–450</td>
<td>1.5–6.7</td>
</tr>
</tbody>
</table>
Fig. 6. More-refined reservoir architecture analyzed of $S_{3}^{1-2}$. 
channels identified, sand body width of 100 m–350 m, sand body thickness of 1.5 m–7.4 m (Fig. 6).

The sediment of braided distributary channel is mainly fine gravel, coarse and medium-fine sandstone in positive rhythm. In the plane, single distributary channels appear in intertwined strips and sheet. Intertwined strip distributary channels exist alone or join with each other laterally. Sheet distributary channels intersect and overlay with each other. There is over-bank sand with poor lithologic and physical properties at the edge of single distributary channel or in the interchannel mudstone.

4.3. Architectural features of single distributary channel sands

Although well spacing of the dense well pattern in the study area is about 100 m, and even 50 m in local part, compared with outcrops, the scale is still large. Hence, the outcrops should be dissected at a smaller scale in order to get an in-depth understanding on the reservoir architecture of the whole gravel braided distributary channel system. The reservoir architecture of dense well pattern was examined in terms of levels of compound distributary channel sands and levels of single distributary channel belts in the above section. Next, the 31st section in Pinglianggou outcrop area in front of Zaire Mountain will be examined from two aspects, scale and superposition pattern of distributary channel sands. There are the same as underground study area, including Formation, sedimentary and reservoir features.

4.3.1. Architecture characterization of the section

Characteristics of lithofacies

Consulting the standard of lithofacies division and plan of [38,39] and [14] based on recognition marks including colors, lithology, grain size, sedimentary structure etc, we have distinguished 9 types of lithofacies in the 31st section of Pinglianggou outcrop (Fig. 7) (Table 3).

![Fig. 7. Typical lithofacies in Pinglianggou No.31 section.](image-url)
A Glutinite with massive bedding (Gm).
Massive bedding also is named homogeneous bedding. Glutinite with massive bedding is almost homogeneous without any laminae structure, which reflects strong hydrodynamic force and fast deposition rate. Dominated by fine conglomerate, this lithofacies contains a lot of boulder clay, and is the product of channel lag deposit in thick massive shape on the whole.

B Fine conglomerate—medium coarse sandstone with trough cross bedding (Gt).
Mainly made up of fine conglomerate, and medium coarse sandstone with large trough cross bedding, this lithofacies is formed by migration of huge sand ridge or sand dune at the early stage of river development when hydrodynamics is strong, so it is big in scale and extension. It is formed by sediment at the bottom of channel.

C Pebby medium coarse sandstone with trough cross bedding (St).
Wide spread on the section, this lithofacies is mainly composed of medium coarse pebbly sandstone with trough cross bedding. Formed by migration of medium-small sand ridges or sand dunes in the middle stage of river development, this lithofacies is small in set scale and lateral extension, and it comes about when flow decreases and flow velocity drops at the river filling stage.

D Pebby medium-coarse sandstone with tabular cross bedding (CSp).
This lithofacies is mainly made up of medium coarse pebbly sandstone, with coarse grains concentrating at the bottom of set, and grains fining upward, reflecting that the hydrodynamics weakens upward gradually. This kind of lithofacies is formed in the period of scour filling period of channel.

E Medium-fine sandstone with cross bedding (Msp).
Mainly developing at the middle stage of distributary channels, this lithofacies is mostly made up of medium-fine sandstone and large in set scale. It is often formed when hydrodynamics is fairly strong and the distributary channel is at steady changing period.

F Medium-fine sandstone with cross bedding (FSp1).
This lithofacies on the interest section is mainly made up of fine siltstone and muddy siltstone. It mainly develops in the fillings of abandoned channel, when hydrodynamics is weakening, but still retains some scour and migration ability.

G Muddy siltstone with parallel bedding (FSp2).
Parallel bedding, the product of water flow near high flow regime, often occurs in high-energy environment with swift and shallow currents. This lithofacies is quite wide spread in the outcrop section in the distributary channels. Mainly made up of medium-fine sandstone, with coarse sand and thin laminae, this lithofacies is formed at scouring-filling stage of channel.

H Silty mudstone with massive bedding (Fm).
In the section, silt mudstone is about 30 cm–50 cm thick, stable in distribution, and scoured by channel developed later in local areas. This lithofacies is mainly mudstone in flood plain.

I Mudstone with massive bedding and coal veins with horizontal bedding (M, Ch).
Distributing on top of the section steadily, it is lake mudstone deposited after distributary channel delta deposition. The mudstone is pure, with horizontal bedding and about 1.5 m thick. The coal veins with horizontal bedding, high in organic matter carbonization level and about 30 cm thick, laminate with thin mudstone layers.

A. Lithofacies of glutinite with massive bedding (Gm): B. Lithofacies of glutinite with trough cross bedding (Gt); C. Lithofacies of sandstone with trough cross bedding and sandstone with large cross bedding (St); D. Lithofacies of coarse sandstone with cross bedding (FSp1); E. Lithofacies of medium-fine sandstone with cross bedding (Msp); F. Lithofacies of fine sandstone-siltstone with tabular cross bedding (CSp); G. Lithofacies of fine sandstone-siltstone with parallel bedding (FSp2); H. Lithofacies of siltstone with massive bedding (Fm); I. Coal vein with horizontal bedding (Ch); J. Mudstone (M)

Features of the outcrop architecture

The 31st section in Pinglianggou is dominated by coarse and medium-fine sandstone, with medium conglomerate and thin mudstone in local areas, representing gravel channel. The detrital particles are good in sorting, sub-rounded or rounded, and high in texture maturity. There develop mainly large trough cross bedding and scouring-filling cross bedding, and parallel bedding, horizontal bedding and scour surface in local parts in the southeast and middle part of the section; while massive cross bedding and parallel bedding mainly in the northwest of the section.

On the section, big 4 level boundary surfaces are well-developed (Fig. 8). There are 6 in total, 4A, 4B, 4C, 4D, 4E and 4F. The main basis to define 4th level boundary surface is that the scale of boundary is relatively large and sedimentary cycle abrupt change is near the boundary; there is fine grained sediment of the abandoning period of sedimentary unit deposited early below the boundary; and the geometry of fairly complete deposit body confined by this boundary surface is lenticular shape flat at top and convex at bottom. The six 4th boundary surfaces mentioned divide the channel into six distributary channels.

Distributary channel unit: This unit has vertical lithofacies association of Gm↔St↔FSp1, and mainly trough cross bedding. The muddy interlayers and diagenesis seepage flow barrier layers of siderite with good continuity at its top are formed the
Fig. 8. Panorama of Pinglianggou NO.31 section (Modified by Jiao, 2005).
abandoning period of the channel. The water was high in energy and fluctuated periodically when this distributary channel formed.

Distributary channel unit I: located on the top of distributary channel unit I, this unit contains mainly lithofacies association of Gt and St, and Gm at the bottom. The mudstone interlayer at its top is not continuous due to the scouring of distributary channel III. With small scale cross bedding as main sedimentary structure, the distributary channel was formed when water was high in energy and cyclic in fluctuation.

Distributary channel unit II: This unit has vertical lithofacies association of CSp2, FSp2, and CSp1 in regular variation, namely with obvious normal grading. With crossing bedding as main sedimentary structure, the unit was formed when paleocurrent energy was weak and in steady reduction.

Distributary channel unit III: This unit has vertical lithofacies association of CSp1→Fh, and sedimentary structures transitional from trough cross bedding at bottom, to parallel bedding, and horizontal bedding at last, reflecting significant reduction in paleocurrent energy during its deposition. This unit is in clear lenticular shape with flat top and convex bottom.

Distributary channel unit IV: This unit has vertical lithofacies association of St→FSp2 in regular variation, namely with obvious normal grading. With crossing bedding as main sedimentary structure, the unit was formed when paleocurrent energy was weak and in steady reduction.

Distributary channel unit V: This unit has vertical lithofacies association of FSp1→Fh, and sedimentary structures transitional from trough cross bedding at bottom, to parallel bedding, and horizontal bedding at last, reflecting significant reduction in paleocurrent energy during its deposition. This unit is in clear lenticular shape with flat top and convex bottom.

Distributary channel unit VI: This unit has vertical lithofacies association of FSp1→Fh→Ch→M. Relatively small in scale, it has the characteristics of lateral migration to northwest. The lithofacies association is FSp1, Fh, Ch and M. At this time, the paleocurrent energy had reduced substantially.

There are 6 distributary channel units developed on 31st section of Pinglianggou. From SE to NW, the lithology changes from coarse sandstone to medium-fine sandstone and then siltstone, with grain size changing from coarse to fine on the whole, while inside a single distributary channel, the grain size changes from coarse to fine from bottom-up. From SE to NW, sedimentary structure changes from big-scale trough cross bedding to small-scale tabular cross bedding to horizontal bedding, reflecting the weakening of paleocurrent energy gradually. Distributary channel I to channel III show the vertical incise of channels. The sedimentary information such as lithological features, sedimentary structures and sedimentary rhythm shows the deposition process of typical channels on the section. From distributary VI to channel VI, the sedimentary features change significantly. For example, the grain size become fine, sedimentary structures change into horizontal bedding, and superposition pattern transforms into lateral superposition. All these changes reflect the channel has entered abandoning period. Therefore, the section can be divided into two major evolution stages, peak development period and abandoning period.

4.3.2. Quantitative scale of distributary channel

Statistics on the single sand parameters of braided river delta distributary channel show the single distributary channel sand on the section is 4.5 m–50 cm wide, 1 m–6 m thick, and 2–9 in width to thickness ratio. As the distributary channels were formed when the provenance supply was sufficient and the channel incise ability is general, the range of the ratio of its width to thickness is relative large (Table 4).

### Table 4

<table>
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4.3.3. Channel superposition patterns

Two main channel superposition patterns have been found out by dissecting the outcrop section (Fig. 9):

① Overlay pattern

The deep overlay pattern refers to the pattern in which multiple periods of distributary channels overlay each other vertically, and the latter distributary channel downcut to the ex-period channel sand. Because of the powerful downcutting, the latter channel will scour the fine sediment on the top of the ex-period channel’s sand. Therefore, the channels are mainly fine conglomerate and coarse sandstone, and not obvious in flat top and convex bottom shape. The mud interlayers between two distributary channels hardly develop, and may only exist at boundary surface, which reflects the paleocurrent energy was powerful. The channels of different periods do not shift much laterally, so the thickness of the channel sand complex can reach over 8 m thick.

② Lateral migration pattern

Lateral migration pattern refers to the pattern in which the distributary channel shifts laterally to a new distributary channel, the lithology is made up of coarse, medium-fine sandstone and siltstone, and the original shape of the channel is preserved basically. Big lateral shift between different channels in this pattern reflects lateral migration of channels and the decline of paleocurrent energy.

4.4. Discussion on the architecture features gravel braided distributary channel and mouth bar

Sedimentary reservoirs in delta are very complex, which is corroborated by a variety of classification schemes for them. The classification based on grain size can reflect the distance from provenance. Because gravel braided distributary channel deltas are close to the provenance, they often feature fairly steep slope and coarse grains, and have braided distributary channels as main architectural element. Although the studies on architectural elements of deltas have focused on two types: distributary channel and mouth bar so far, there are few researches investigating the conversion mechanism from distributary channels to mouth bars and the features of the transiting belt from modern deposition and outcrops. Available modern deposition and outcrop data shows the study degree of distributary channels is higher than that of mouth bars, therefore, on the basis of the existent knowledge on distributary channels, the formation mechanisms of mouth bars under different conditions, especially the different transform mechanisms of different types of distributary channels to mouth bars should be investigated to deepen the understanding on deltas.

5. Conclusions

Through the above study, we reach the following conclusions:

(1) The main reservoir architecture elements in gravel braided deltas are distributary channel and overbank sand, the main reservoir flow barrier elements are interchannel mudstone and lacustrine mudstone. Different architecture
elements are different widely in characteristics of core, log response and sedimentary structure.

(2) Gravel braided distributary channel sand complexes (6 level) are in three kinds of shapes, sheet, interweaving strip and single strip, and sands of different shapes are different in scale. Sheet sands of distributary channel appearing in big pieces on the plane are about 1500 m in scope, and 1.5 \( \times \) 7.4 m in thickness; interweaving strip sands are 500 \( \times \) 1000 m in scope, and 1.5 \( \times \) 7.6 m in thickness on the plane; single strip distributary channel sands are 300 \( \times \) 500 m in scope and 1.5 \( \times \) 5 m in thickness.

(3) The recognition marks of single distributary channels (5 level) are top surface depth displacement of distributary channel sands, lateral superposition of distributary channel sands, feature of “thick-thin-thick” of distributary channel sand thickness, interchannel mudstone or overbank sand appearing between distributary channels and differences in logging curve features of distributary channel sands.

(4) Nine kinds of lithofacies have been identified in the distributary channel units (4 level) in the study area, Gm, Gt, St, CSp, MSP, FSp1, FSp2, Fm, M, and Ch. Different channel units have different lithofacies assemblages. The outcrop section contains 6 distributary channel units which appear in two combination patterns, overlay pattern and lateral migration pattern.

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References


