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Research paper

Paleotopographic controls on facies development in various types of braid-delta depositional systems in lacustrine basins in China

Dong Feng [a,*], Hongwen Deng [a], Zhan Zhou [b], Xiaopeng Gao [c], Longtao Cui [a]

[a] School of Energy Resources, China University of Geosciences (Beijing), No.29 Xueyuan Road, Haidian District, Beijing 100083, China
[b] Zhanjiang Branch of China National Offshore Oil Corporation Ltd, Zhanjiang 524057, China
[c] SINOPEC Exploration and Production Research Institute, Beijing 100083, China

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A B S T R A C T

Braid-delta depositional systems are widely developed in most continental basins in China. Research indicates that, for different types of braid delta, the facies sequence and association, which are critical to the prediction of the distribution of reservoirs, differ greatly. This study illustrates the differences in braid-delta depositional systems in terms of sedimentary characteristics, associated systems and reservoir distributions using three typical paleodeltas in western China: the Zhenbei delta of the upper Triassic Yanchang Formation in the Ordos Basin, the Yuanba delta of the upper Triassic Xujiahe Formation in the Sichuan Basin and the Jimsar delta of the upper Permian Wutonggou Formation in the Junggar Basin. A stratigraphic framework was established using seismic data, logs and cores by choosing stable mud sections as regional correlation markers and, topographies of these deltas were reconstructed based on the decompaction and paleobathymetric corrections. Based on both the paleotopography of these deltas and the differences of their sedimentary facies, these braided deltas can be classified into two systems: steep-gradient braid-delta-turbidite system and low-gradient braid-delta-lacustrine system. Moreover, the low-gradient braid-delta-lacustrine system can be further divided into interfingered and sharp contact sub-types according to the contact relation between the delta sands and lacustrine muds. This study shows that the paleotopography of basin margins strongly controls the accommodation as braid deltas prograde into lacustrine basins and, influences the location of the shoreline in response to changes in the lake level. Furthermore, paleotopography plays a significant role in facies and reservoir distribution which is important for petroleum exploration and development.

1. Introduction

Braid deltas were previously classified as fan deltas (McGowen, 1971; Bates and Jackson, 1980; Galloway and Hobday, 1983; Nilsen, 1985). However, there are significant differences between braid deltas and fan deltas, such as their mechanisms of generation, geomorphic features and sedimentary environments. McPherson et al. (1987) described separately and after than most of researchers agree that braid deltas are formed by the progradation of braided fluvial system into a standing body of water, are composed primarily of laterally coalesced fluvial sands and gravels and are interbedded with finer-grained marine or lacustrine deposits (McPherson et al., 1987; Dunne et al., 1988; Soegaard, 1990; Xue and Galloway, 1991). Recent studies demonstrate typical characteristics of braid deltas in different depositional settings, such as their original geomorphology, sediment supply and the reworking processes (Eriksson et al., 1995; Hamlin et al., 1996; Macnaughton et al., 1997; Lemons and Chan, 1999; George, 2000; Zou et al., 2010).

There are different views about the controlling factors of braid-delta deposition in basin margins. For example, Lemons and Chan (1999) noted that under relatively stable tectonic conditions, basin paleotopography is an important contributor to depositional systems in continental basins. Other studies equate the depositional system of braid deltas with that of common deltas (Li et al., 2001; Shao et al., 2005; Zhu et al., 2008). There have been relatively few studies comparing the deposition of braid deltas developed in different basin margins, which caused some debate in

* Corresponding author. Tel.: +86 13426137098.
E-mail address: fdong821@sina.com (D. Feng).
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depositional systems and reservoir distributions within these types of deltas (Posamentier and Allen, 1993; Shanley and McCabe, 1994; Lemons and Chan, 1999; Yagishita and Takano, 2005; Zhang et al., 2008; Zou et al., 2010; Zhu et al., 2013).

So far, the debate about lacustrine braid deltas has mainly focused on the following concepts: (1) May braid deltas form when braided fluvial systems prograde into lakes (Dunne et al., 1988)? (2) May braid deltas develop three sets (topset, foreset and bottomset), similar to common deltas (Guo, 2012; Zhu et al., 2013)? (3) May turbidite systems develop in a foredelta (Posamentier and Allen, 1993; Lemons and Chan, 1999; Zhu et al., 2013)? (4) What are the differences in the vertical sequence and facies in different types of braid delta and what are the main controlling factors (Lemons and Chan, 1999; Li et al., 2001; Shao et al., 2005; Zhu et al., 2008; Zou et al., 2010)? Therefore, the Zhenbei delta in the upper Triassic Yanchang Formation in the Ordos Basin, the Yuanba delta in the upper Triassic Xujiahe Formation in the Sichuan Basin and the Jimsar delta in the upper Permian Wutonggou Formation in the Junggar Basin provide an excellent opportunity to study these issues.

The purpose of this study is to document the influence of the paleotopography of basin margins and to compare the properties of depositional systems in different styles of braid deltas. The tectonics, climate, sediment flux, lake level and basin paleotopography of these depositional systems provide a model for hydrocarbon reservoir exploration of lacustrine subsurface deposits where many of these controlling parameters are generally unknown or poorly understood.

2. Geological setting

The Ordos, Sichuan and Junggar basins are the most important continental basins in western China (Fig. 1). The Ordos and Sichuan basins are in the western margin of the North China plate and the Yangtze plate, respectively. The tectonic movements of these basins are controlled by regional uplifting and subsidence (Chen et al., 2001; Zhang et al., 2007). The Ordos Basin and Sichuan Basin fully evolved into lake basins due to the regional collisional tectonism and related intra-plate deformation in the late Triassic (Fig. 2). The Junggar Basin, located in the eastern part of the Junggar–Kazakhstan plate, is bounded by the Altai orogenic belt to the north and the Tianshan orogenic belt to the south. Two tectonic stages had been effective in this basin: a rifting stage in the Permian and a sagging stage from the Triassic to the late Eocene (Han et al., 2001; Lu et al., 2008). During late Permian, Junggar Basin underwent a rift-sagging transition period and was dominated by lacustrine deposition (Fig. 2).

The Zhenbei delta of the upper Triassic Yanchang Formation developed as a result of both sediment supply from the southwest and the west of the Ordos Basin and unactivated faults and folds. This delta occupies an area of nearly 8×10^3 km^3 (Wei et al., 2003; Chen et al., 2009).

The Yuanba delta of the upper Triassic Xujiahe Formation is situated in the north part of the Sichuan Basin and formed on a surface with gentle structural deformations where fewer faults developed. It covers an area of approximately 1.7×10^3 km^3. Its feeder systems are mainly from the north and the northeast of the Sichuan Basin (Jiang et al., 2007).

The Jimsar delta of the upper Permian Wutonggou Formation lies in the southeast of the Junggar Basin and has an area of approximately 1.3×10^3 km^3. It was fed from the southwest of the Junggar basin. Seismic reflections have shown that there is little change in the thickness of the Wutonggou Formation as it dips toward the west (Guo, 2012).

3. Paleotopography reconstruction

The paleotopography of the basin margins and its significance on the paleogeography of sedimentary basins has recently been a popular topic in sedimentary geology and basin analysis. It has also proven to be a useful tool in paleogeographic analysis and reservoir prediction (Plint and Wadsworth, 2003; Posamentier and Kolla, 2003; Deptuck et al., 2007; Green, 2009; Lin et al., 2009; Glørstad-Clark et al., 2010; Pandey et al., 2010; Liu et al., 2012).

Paleotopography, as used here, refers to the angle and length of the depositional surface (which is also called ramp) on which each paleodelta was deposited. The process of reconstructing the paleotopography of the ramp is illustrated as case study of the Zhenbei delta by including stratigraphic correlation, restoration for erosion, decompaction and paleobathymetric correction.

3.1. Stratigraphic correlation

Accurate correlation of stratigraphy is the basic requirement for paleotopography reconstruction. The most reliable correlation markers are widespread within a mudstone section, deposited during lacustrine flooding period (Xue and Galloway, 1993; Shanley and McCabe, 1994; Fanti and Catuneanu, 2010).

The upper Triassic Yanchang Formation, between the boundaries of Ch6 and Oil shale, can be divided into two units, the Ch6 unit and Ch7 unit, which are separated by stable mud (Ch7). Each unit can be further divided into several subunits by the inter-mud (Fig. 3).

3.2. Method of paleotopography reconstruction

(1) **Restoration for erosion.** There are many methods for restoration of eroded strata (Wyllie et al., 1956; Magara, 1976; Kumar, 1979; Henry, 1996; Lin et al., 2009; Liu et al., 2012). Extended seismic reflection configuration method has been widely applied for its simplicity and efficiency. The erosion was estimated from the seismic reflection configuration and from well log comparison, using the principle of the similar thickness trends in adjacent strata.

During the late Triassic, the Ordos Basin was a stable craton depression. The Yanchang Formation was a sequential deposition in this area. There was no unconformity or erosion in the study units; therefore, restoration for erosion could be ignored.

(2) **Decompaction correction.** We did not simply flatten Ch6 and calculate the thickness of the unit between Ch6 and Oil shale, because the thickness and ratio of sand to mud differs from the delta plain to lake in delta systems, which cause great differences in the degree of compaction at the different regions. Therefore, a decompaction correction is necessary to calculate the original thickness from data at the present burial depths.

Under normal compaction conditions, the relationship between porosity and burial depth of a deposit can be expressed by an exponential function (Athy, 1930; Perrier and Quiblier, 1974):

$$\varphi = \varphi_0 e^{-ch} \tag{1}$$

where φ is the porosity at burial depth h, φ_0 is the depositional porosity and c is the compaction coefficient.

Based on measured porosity data from 60 wells, curves that reflect the relationship between porosity and burial depth were formulized for various lithologies.

Mudstone:

$$\varphi = 0.5947e^{-0.000762h} \tag{2}$$

Sandstone:

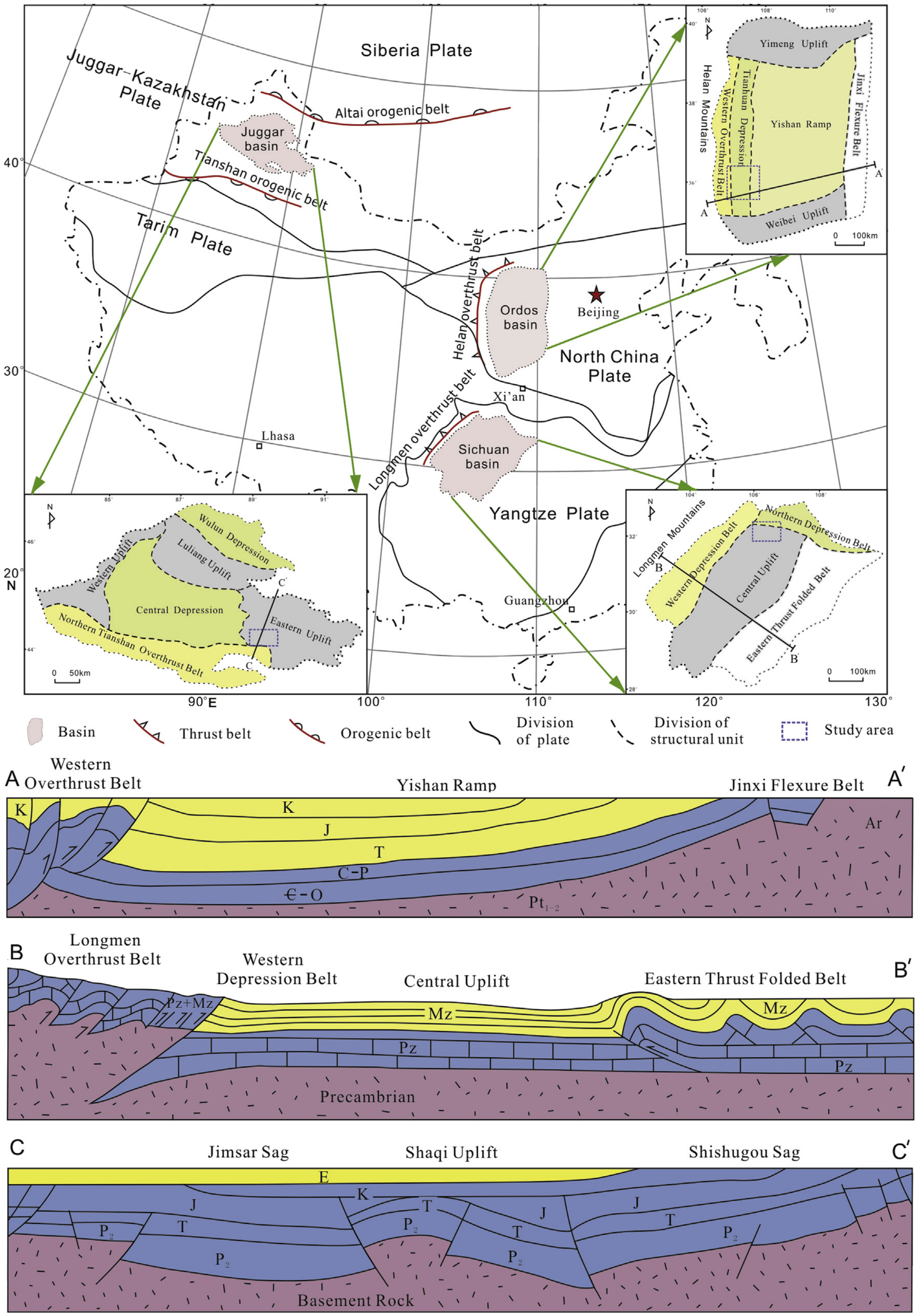

Figure 1. Map and stratigraphic sections of the study basins (modified from Liu et al., 2006).

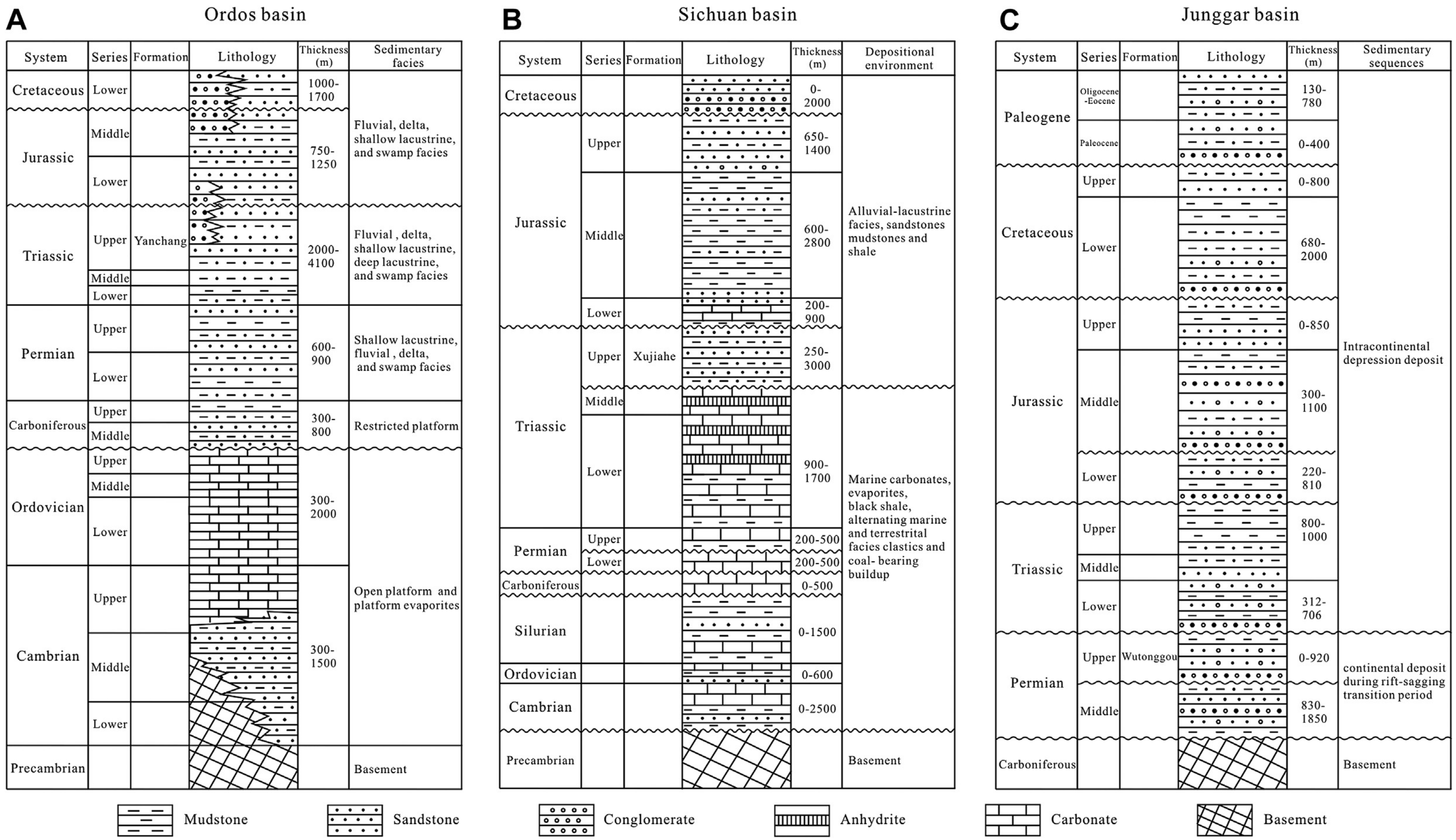

Figure 2. Stratigraphic columns and combination of depositional systems (modified from Cai et al., 2003; Zhang et al., 2006; Jin et al., 2008).

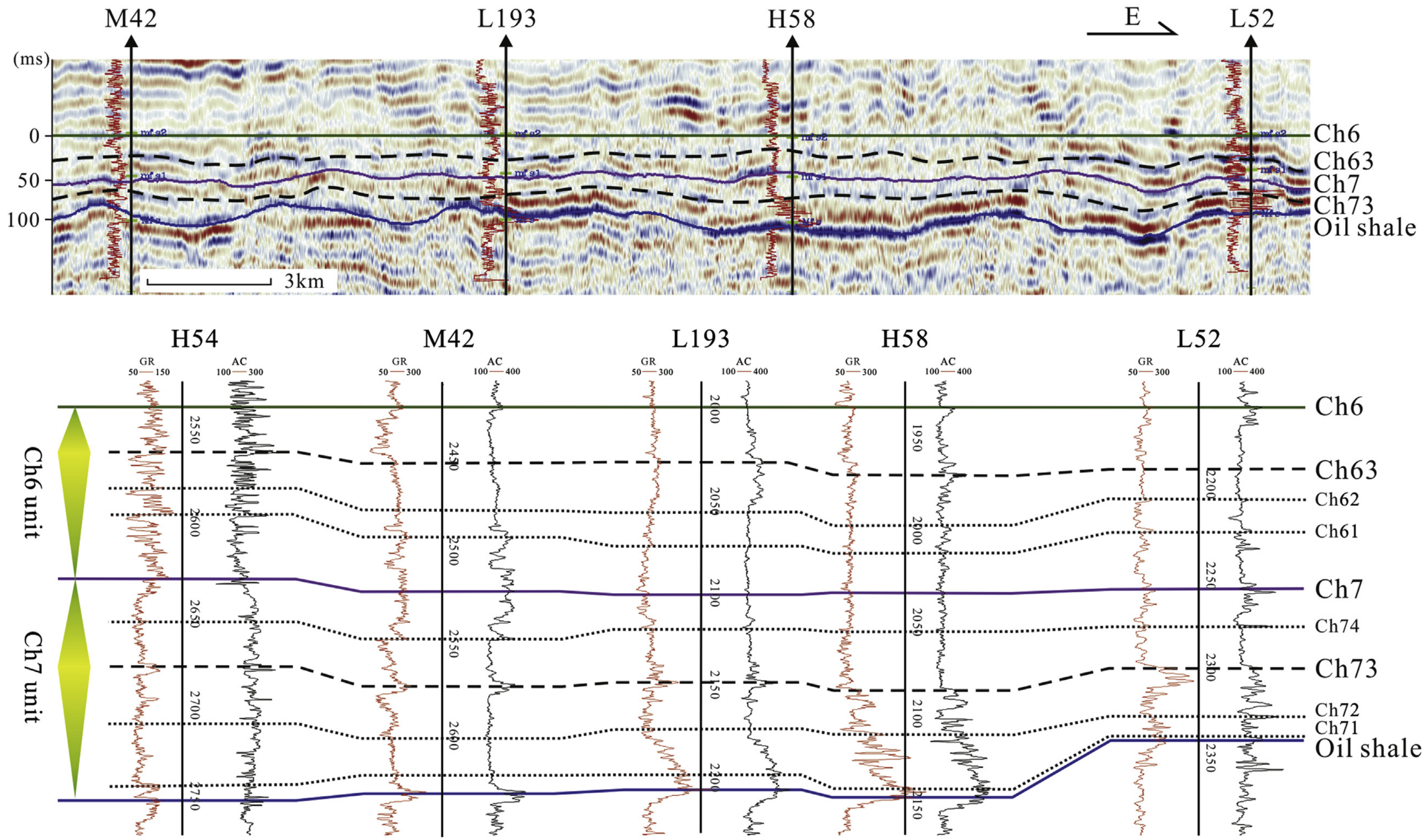

Figure 3. Well correlation of the Zhenbei delta, Yanchang Formation, lying between Ch6 and Oil shale, Ordos Basin (see Fig. 6 for location).

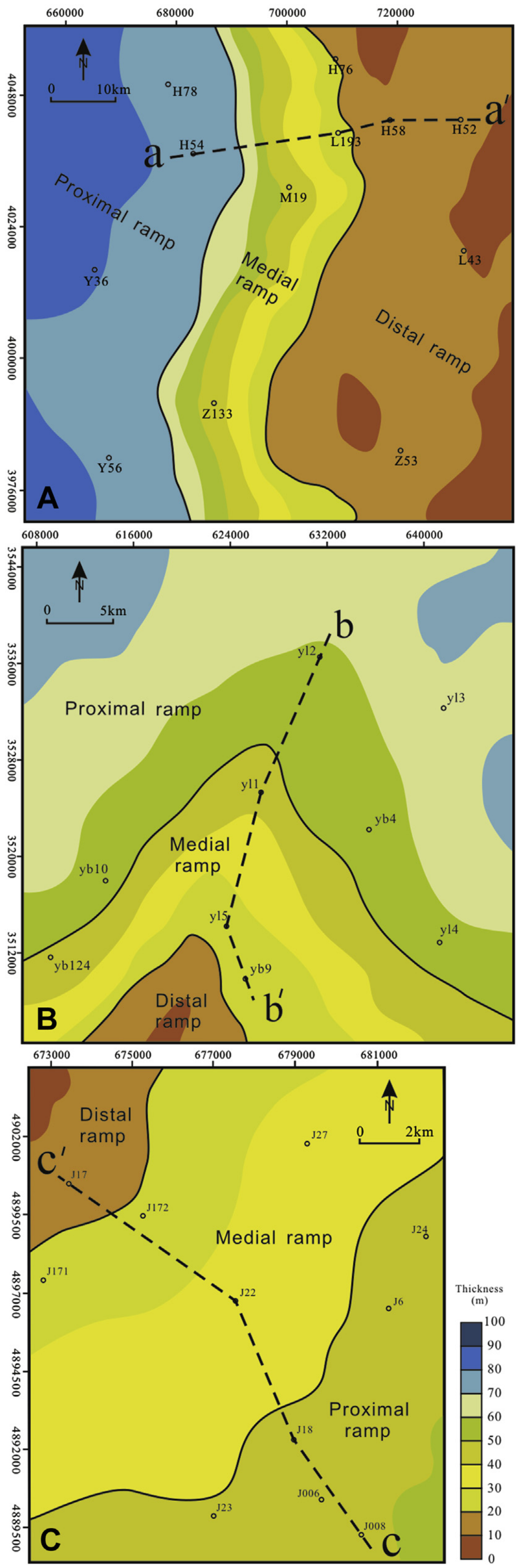

Figure 4. Reconstructed paleotopography of the three paleodeltas. (A) The paleotopography of the depositional surface (oil shale) prior to deposition of the Zhenbei delta, Ordos Basin, Yanchang Formation (see Fig. 6A for location a–a′); (B) the paleotopography of the depositional surface (bottom mud) prior to deposition of the Yuanba delta, Sichuan Basin, Xujiahe Formation (see Fig. 8A for location b–b′); (C) the paleotopography of the depositional surface (bottom mud) prior to deposition of the Jimsar delta, Junggar Basin, Wutonggou Formation (see Fig. 10A for location c–c′).

$$\varphi = 0.4906e^{-0.000442h} \tag{3}$$

In the process of compaction, the volume of sediment grains remains constant; the only volume loss is pore volume (Lu and Tian, 1991; Sciunnach and Garzanti, 2012). We assumed the burial depths of the deposits are h_1 at its top and h_2 at its bottom, so that as the deposit flattens to its initial depositional surface, the original burial depth (H) of the deposit can be expressed by

$$H = h_2 - h_1 - \frac{\varphi_0}{c}\left(e^{-ch_1} - e^{-ch_2}\right) + \frac{\varphi_0}{c}\left(1 - e^{-cH}\right) \tag{4}$$

(3) **Paleobathymetric correction.** Lithofacies changes considerably along the surface Ch6, from subaerial to subaqueous. The thickness of the original deposit must be corrected according to the paleobathymetry data (Lin et al., 2009; Sciunnach and Garzanti, 2012). The paleobathymetric correction may need the integrated analysis of benthic microfossils, trace fossils, depositional facies and distinctive geochemical signatures. Sources for paleobathymetric data in this area primarily rely on sedimentary structures because of the lack of ichnofacies. Generally, the paleodepth of large-scale cross-bedding is 0.5–5 m, that of ripples and horizontal laminations is 5–20 m, and the paleodepth of the Bouma sequence and hummocky cross-stratification is >30 m (Zhang and Ren, 2003).

The credibility of paleotopographic reconstructions that were calculated from misted wells in the study area is high. The paleotopography of the depositional surfaces (Oil shale) prior to the deposition of the Zhenbei delta has been reconstructed by integration of present residual thickness, decompaction and paleobathymetric corrections (Fig. 4A).

4. Ramp characteristics

Ramps on the continental basin margins, owing to the stable tectonics, strong fluvial action and low tidal and wave forcings there, are prone to the development of the numerous braid-delta depositional systems and, to control facies development in these deltas (Postma, 1990; Posamentier and Allen, 1993; Lemons and Chan, 1999; Yagishita and Takano, 2005).

Using the method of paleotopographic reconstruction described above, the paleotopography of the three deltas were calculated and mapped here (Fig. 4).

The ramp of the Zhenbei delta is characterized by a relatively steep-gradient. This is especially true of the middle ramp, which has a nearly north-south trend and dips 70 m basinward over 10 km, for a gradient of approximately 0.45°. The proximal and distal ramps are rather gentle, with gradients less than 0.1°.

The gradient of the middle ramp in the Yuanba delta is approximately 0.16° and is steeper than the proximal and distal ramps, with a nearly east-west trend that dips 40 m over 15 km.

The ramp in the Jimsar delta is characterized by a relatively low-gradient of approximately 0.09°. There are no significant changes throughout the ramp, which is longer than 20 km in length.

According to studies of the ramp angle and length by Postma (1990), Lemons and Chan (1999) and Porębski and Steel (2003), the Zhenbei delta is classified as steep-gradient delta, whereas the Yuanba delta and Jimsars delta as low-gradient deltas.

5. Types of braid-delta depositional systems

The classification of deltas were introduced during the 1970s (Coleman and Wright, 1975; Galloway, 1975; McPherson et al., 1987; Postma, 1990; Orton and Reading, 1993), but there has been less research on braid deltas. Our studies of the three paleodeltas permit to subdivide braid-delta depositional systems into types and sub-types described below.

Table 1
Detailed descriptions of facies of braided deltas.

Facies associations	Lithofacies and colors	Sedimentary structures	Unit thickness (m)	Depositional environment
Braided channel[abc]	Fine- to coarse-grained sandstone, conglomerate, coal; gray	Erosional base, trough cross-bedding, massive bedding, parallel bedding	Superimposing units reach tens of meters, each unit ranges in 3–6 m	Braided fluvial channels
Floodplain[abc]	Mudstone and siltstone; gray, rarely green or red	Massive bedding, current ripples	1–10 m	Flooding plain
Subaqueous distributary channel[abc]	Very fine/fine- to coarse-grained sandstone, rarely conglomerate; gray, dark gray	Low-angle cross-bedding, massive bedding, parallel bedding, current/wave ripples	Less or no superimposing, ranges in 2–5 m	Shallow lake
Mouth bar[abc]	Very fine to medium-grained sandstone, siltstone; gray, dark gray	Low-angle cross-bedding, current/wave ripples, locally soft-sediment deformation	1–4 m	Shallow lake
Sand sheet[abc]	Siltstone, interbedded fine sand and mud; gray, dark gray	Current/wave ripples, horizontal lamination	1–2 m	Shallow lake or semi-deep lake
Turbidite[a]	Very fine to medium-grained sandstone, siltstone; gray, dark gray	Massive bedding, current/wave ripples, soft-sediment deformation	Meters to tens of meters	Shallow lake
Lacustrine deposit[abc]	Mudstone and siltstone; gray, dark gray, dark	Current/wave ripples, horizontal lamination	Meters to tens of meters	Shallow lake to deep lake

(a) Representation of facies recognized in the Zhenbei delta. (b) Representation of facies recognized in the Yuanba delta. (c) Representation of facies recognized in the Jimsar delta.

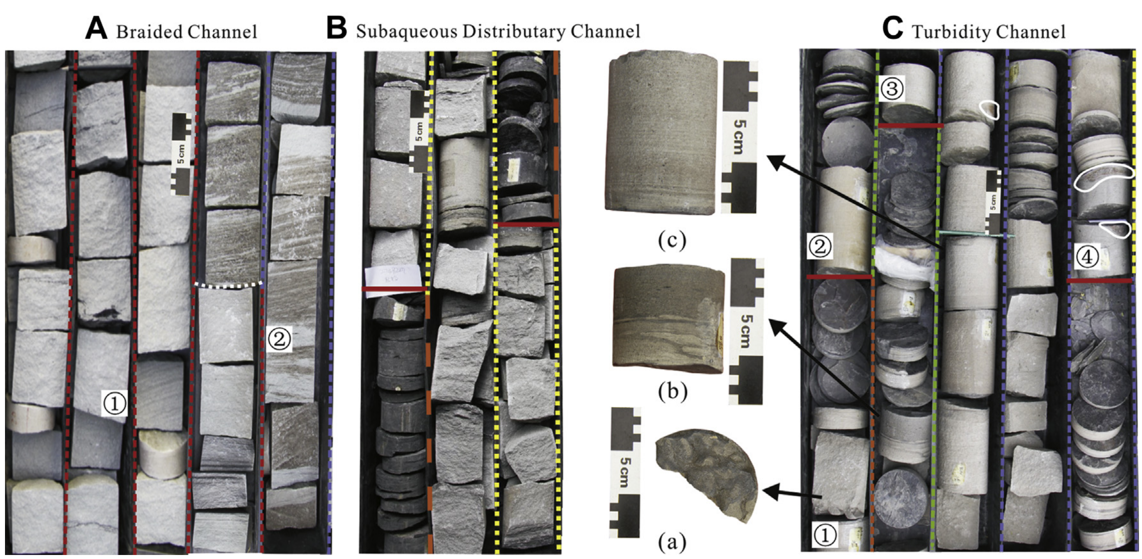

Figure 5. Core photographs of representative facies in the Zhenbei delta. (A) Two units of superimposed braided channel with an erosional contact (2726.8–2730.3 m, H54); (B) subaqueous distributary channel (dotted line) with a sharp contact with dark lacustrine mudstone (dashed line) (2171.2–2173.6 m, L193); (C) four periods of superimposed turbidity channel. Typical structures are load (a), deformation (b), block (c), and floated gravel (white circle).

5.1. Steep-gradient braid-delta-turbidite system

Facies associations developed in the Zhenbei delta were braided channels, floodplains, subaqueous distributary channels, mouth bars, sand sheets, turbidites and lacustrine deposits (Table 1). Turbidity deposits were found only in the Zhenbei delta.

Braided channels can be tens of meters thick; they consist mainly of the delta plain and are characterized by superimposed thinning-upward channelized units. Each unit has an erosional surface, is 3–6 m thick and is often marked by a lag deposit (Fig. 5A). Thin-bedded gray mud, formed during flooding, is the uppermost unit that caps the braided channel. Subaqueous distributary channels are the underwater extension of braided channels. Their thicknesses range from 2 to 5 m. Subaqueous distributary channels are characterized by little to no superimposing channel deposits and a sharp contact with dark lacustrine mudstone (Fig. 5B). Mouth bars and sand sheets occupy large volumes in the delta front. The turbidity deposits, located in front of the mouth bars and sand sheets, primarily consist of turbidity channels sediments and turbidity sheet sands (Fig. 5C).

The sedimentology of the Zhenbei delta was influenced by its short, steep ramp (Fig. 6). Minor progradation and retrogradation of the delta on the steep ramp causes minor shoreline migration. Like in a common delta, three sets (topset, foreset and bottomset) are well developed in the Zhenbei delta. The bottomset comprises turbidity and lacustrine mud deposits. As the delta progrades, the mouth bars and sand sheets partly superimpose on the turbidity deposits. The maximum thickness of a single period of delta sand is approximately 20 m. The layer between Ch6 and Oil shale is wedge-

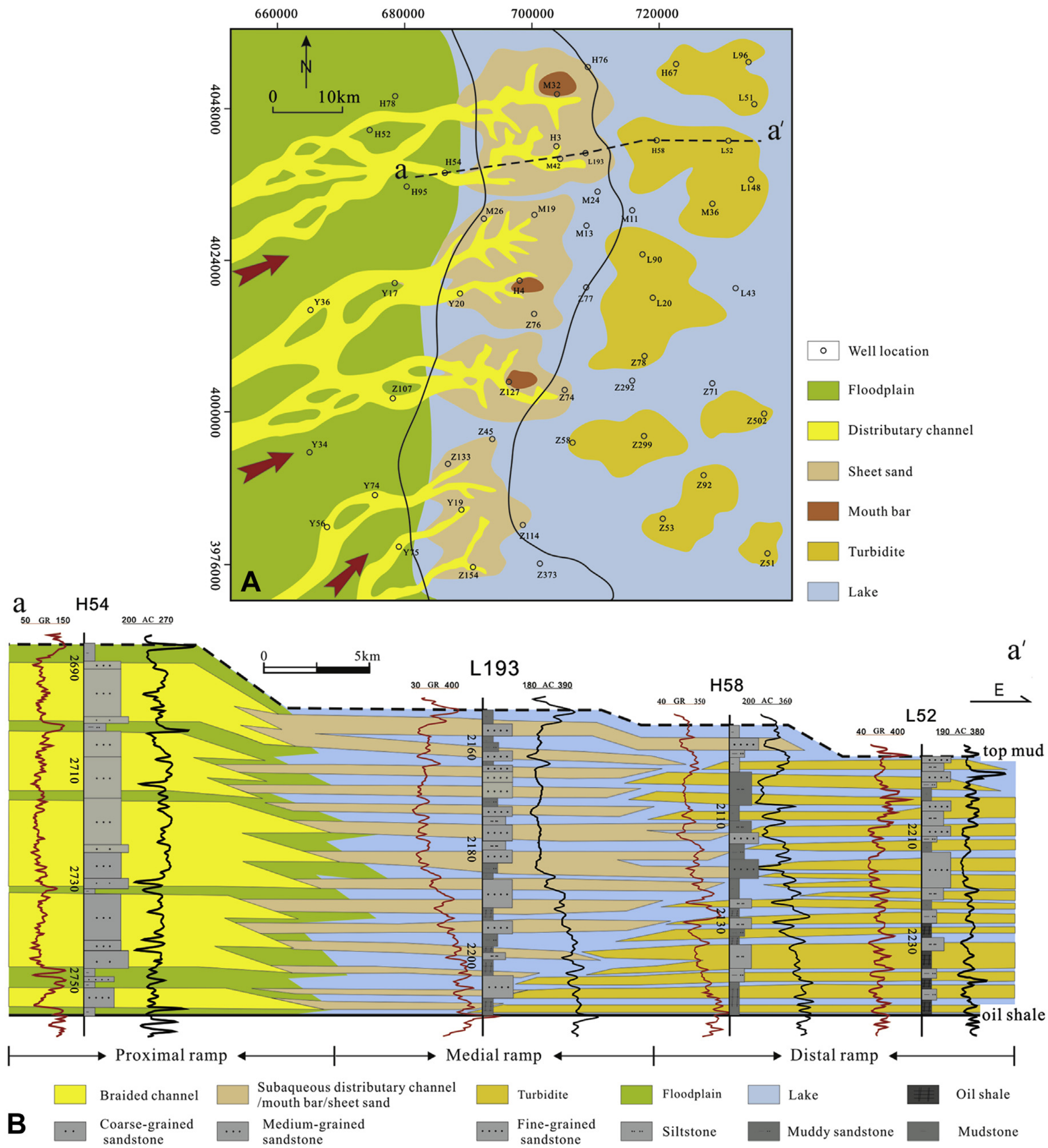

Figure 6. Reconstructed paleotopography and the distribution of sedimentary systems in plane view (A) and in vertical successions (B) of the Yanchang Formation within the Zhenbei delta, Ordos Basin (see Fig. 6A for location a–a′).

shaped and thins basinward (Fig. 6B). Channel sandbodies in the delta plain are belt-like, whereas they are widely distributed and sheet-shaped in delta front (Fig. 6A).

5.2. *Low-gradient braid-delta-lacustrine system*

The Yuanba delta and Jimsar delta belong to low-gradient braid-delta-lacustrine systems. According to the different contacts between the delta sands and lacustrine muds, the low-gradient braid-delta-lacustrine systems can be further divided into two sub-types: interfingered and sharp contact sub-systems.

5.2.1. *Interfingered contact sub-system*

Six facies associations were identified in the Yuanba delta, including braided channels, floodplains, subaqueous distributary channels, mouth bars, sand sheets and lacustrine deposits (Table 1, Fig. 7).

The degree of superimposition of braided channels is low in the Yuanba delta. The thickness of floodplain muds is high ranging from 5 to 10 m. Subaqueous distributary channels become much narrower, and the distance they extend gets shorter accordingly. The lacustrine mud is widely distributed on the prodelta, especially without turbidity deposits (Fig. 8).

Because of the low-gradient ramp, even very small fluctuations in the lake level can cause large-scale migration of the shoreline (Fig. 8). There is more larger-scale interfingering between the delta front and lacustrine mud deposits in comparison to the Zhenbei delta. Although three sets (topset, foreset and bottomset) are still developed here, the bottomset is mainly composed of lacustrine mud deposits and lacks turbidity deposits. Braided channels are

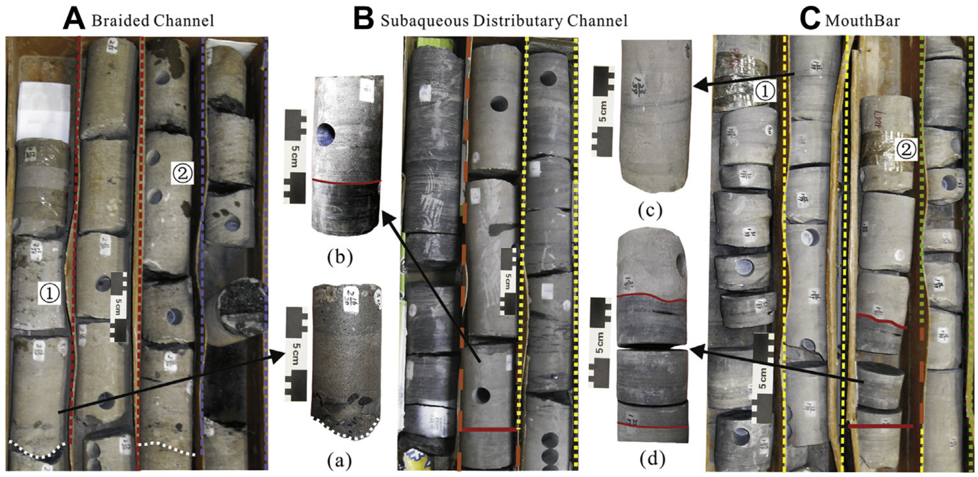

Figure 7. Core photographs of representative facies in the Yuanba delta. (A) Two units of superimposed braided channels with an erosional contact (a) (4589.3–4593 m, yl2); (B) subaqueous distributary channel (dotted line) with a sharp contact (b) with dark lacustrine mudstone (dashed line) (4250.1–4253 m, yl5); (C) two periods of superimposed mouth bars; typical structures are low-angle cross-bedding (c), load structures and sharp-contact surfaces on the top of mouth bar (d) (4232.3–4236 m, yl5).

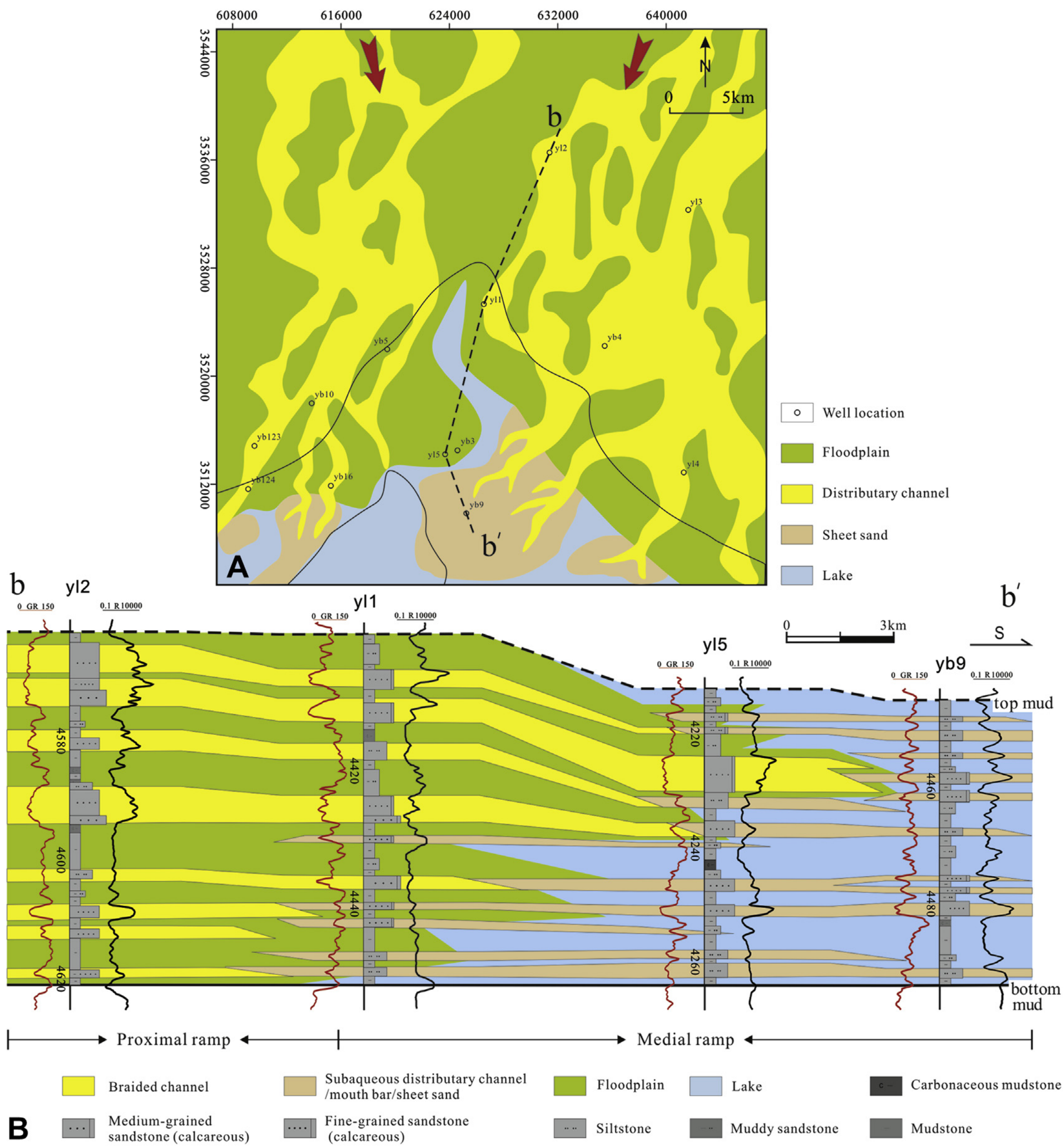

Figure 8. Reconstructed paleotopography and the distribution of sedimentary systems in plane view (A) and in vertical successions (B) of the Xujiahe Formation within the Yuanba delta, Sichuan Basin (see Fig. 8A for location b–b′).

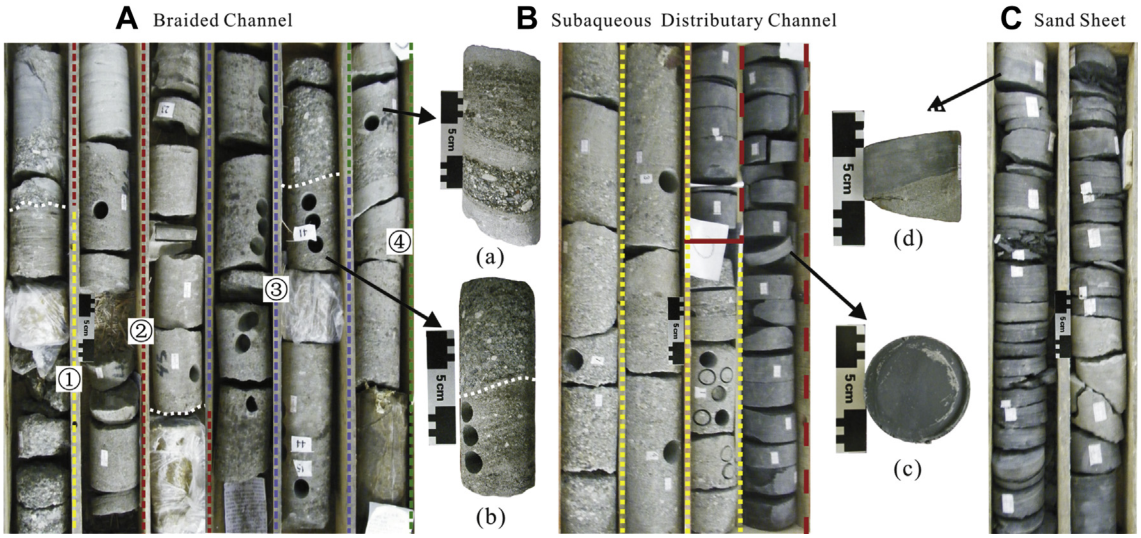

Figure 9. Core photographs of representative facies in the Jimsar delta. (A) Interbeded conglomerate and sand (a) developed in superimposed braided channels with an erosional contact (b) (1586.5–1592.5 m, J008); (B) subaqueous distributary channels (dotted line) in sharp contact with dark lacustrine mudstone (c) (dashed line) (2336.5–2340.5 m, J22); (C) thin-bedded siltstone in sharp contacted (d) with lacustrine mud in sand sheet deposits (2948–2950 m, J17).

superimposed on delta-front mouth bars and sand sheets, which indicates progradation of the delta. The maximum thickness of a single period of delta sand for the Yuanba delta is approximately 10 m (Fig. 8B). The area occupied by the delta plain is wider than this in the Zhenbei delta, but it becomes narrower in the delta front. The channel sandbodies belt broadens in the delta plain (Fig. 8A).

5.2.2. Sharp contact sub-system

Facies associations of the Jimsar delta could be summarized as braided channels, floodplains, subaqueous distributary channels, mouth bars, sand sheets and lacustrine deposits (Table 1, Fig. 9).

As in the Yuanba delta, the degree of superimposition of braided channels decreases in the Jimsar delta, as does the thickness of each channelized units, to approximately 2–4 m. Subaqueous distributary channels and mouth bars are poorly developed, whereas thin-bedded sand sheets are widespread at the delta front. The turbidity deposits are not developed in the prodelta (Fig. 10).

With the further reductions in ramp gradient, the sedimentology of the Jimsar delta is quite different than that of the Zhenbei and Yuanba deltas (Fig. 10). Because of the frequent migration of the shoreline, the lacustrine mud is interbedded with braided channel. The layer between bottom mud and top mud has little change in thickness, and it is very difficult to discriminate the foresets and bottomsets (Fig. 10B). Owing to the frequent swing, channel sandbodies are widely distributed and sheet-shaped both in the delta plain and at the delta front, which is missing turbidity deposits (Fig. 10A).

6. Paleotopography *versus* braided delta system

The differences in ramp gradients (specifically ramp angles and lengths) have a significant effect on the migration of the shoreline, and subsequently determine the accommodation (the space made available for potential sediment accumulation) and distribution of depositional systems (Fig. 11). The Zhenbei delta has steep angles and short ramps, so the accommodation is mainly located in front of ramp. Fluvial incision and continued accumulation of sediments result in unstable ramps along the basin margins, and a series of landslides occurred along the ramp. On the other hand, the Yuanba and Jimsar deltas have relatively low angles and long ramps, so their accommodation varies corresponding to the location of the shoreline, resulting in thinner, patchy deposits of channel sandbodies. There are no turbidity deposits in low-gradient deltas.

7. Discussion

The parameters governing the development of depositional systems and reservoir distribution are tectonics, climate, sediment-flux rates, lake level and paleotopography (Orton and Reading, 1993; Posamentier and Allen, 1993; Shanley and McCabe, 1994; Miall, 1996; Carroll and Bohacs, 1999; Lemons and Chan, 1999).

Tectonism is an important factor in building the paleotopography of a basin margin (Posamentier and Allen, 1993; Lemons and Chan, 1999). The Yanchang Formation was influenced by regional collision in the late Triassic; the region was subjected to compressive deformation prior to the deposition of the Zhenbei delta, which allowed the delta to form on a steeper ramp in the Ordos Basin (Deng et al., 2008). Unlike in the Ordos Basin, the regional collision had little effect on the ramp prior to the deposition of the Yuanba delta in the Sichuan Basin. The area around the Jimsar delta was controlled by normal faults in the late Permian; the delta thus formed on a gentle ramp.

In lacustrine basins, changes in lake level affect lacustrine stratigraphy regardless of whether the lake is hydrologically open or closed (Shanley and McCabe, 1994). However, in an overfilled lake, the effect of climate on lake level is minimal (Carroll and Bohacs, 1999). The sediment-flux rates of the Zhenbei delta were 30 m/Ma, which are larger than the subsidence rates of 8.38 m/Ma in the late Triassic (Wang et al., 2009). The sediment-flux rates of the Yuanba delta in the late Triassic and the Jimsar delta peaked in the late Permian (Liu and Chang, 2003; Chen and Wang, 2004). Thus, climate has little effect on the fluctuation of the lake levels at all three deltas.

During the development of depositional systems in the three braid deltas, paleotopography had more significant control on the sedimentary systems and reservoir distributions than did the other forcing parameters. This finding is consistent with the suggestion of Posamentier and Allen (1993) and Lemons and Chan (1999) that paleotopography determines the internal organization of the strata between bounding surfaces.

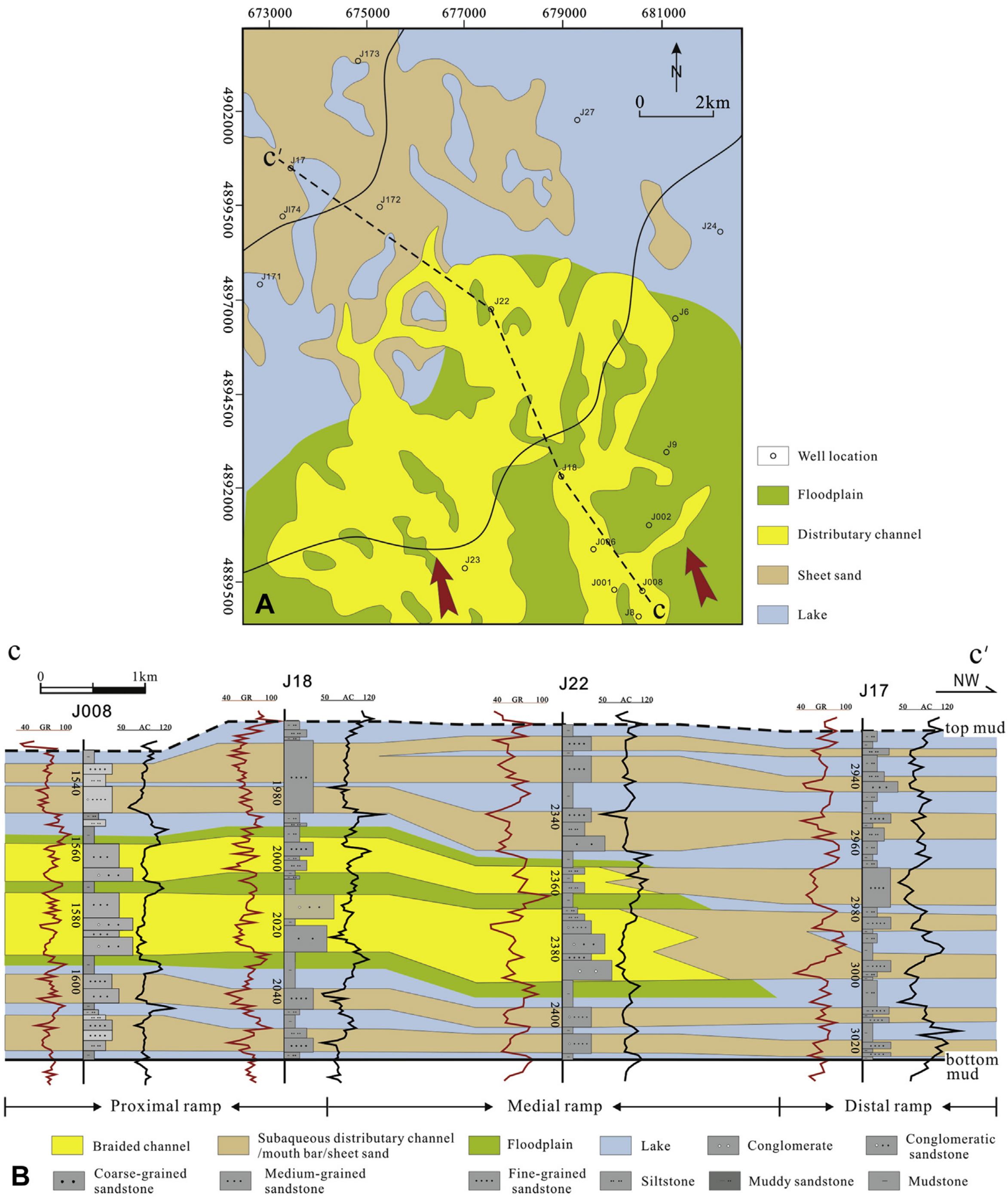

Figure 10. Reconstructed paleotopography and the distribution of sedimentary systems in plane view (A) and in vertical successions (B) of the Wutonggou Formation within the Jimsar delta, Junggar Basin (see Fig. 10A for location c–c′).

8. Conclusions

Using the current residual thickness and decompaction and paleobathymetric corrections, the paleotopography of the ramps in three deltas were reconstructed. The Zhenbei delta is characterized by a short, steep-gradient ramp, especially the middle ramp. The Yuanba and Jimsar deltas are characterized by long, relatively low-gradient ramps. There are no significant changes throughout the ramp in the Jimsar delta.

These three typical braid deltas are representative of braid-delta depositional systems that develop under relatively stable tectonic conditions in continental basins, which can be classified into steep-gradient braid-delta-turbidite system and low-gradient braid-delta-lacustrine system. Moreover, according to the different types of contacts between the delta sands and lacustrine muds, the low-gradient braid-delta-lacustrine system can be further divided into interfingered and sharp contact sub-systems.

The Zhenbei delta is a typical steep-gradient braid-delta-turbidite system, composed of delta deposits, turbidite sands and lacustrine deposits. In contrast, the Yuanba and Jimsar deltas are low-gradient braid-delta-lacustrine systems, and include delta and lacustrine deposits. The distinguishing characteristic between

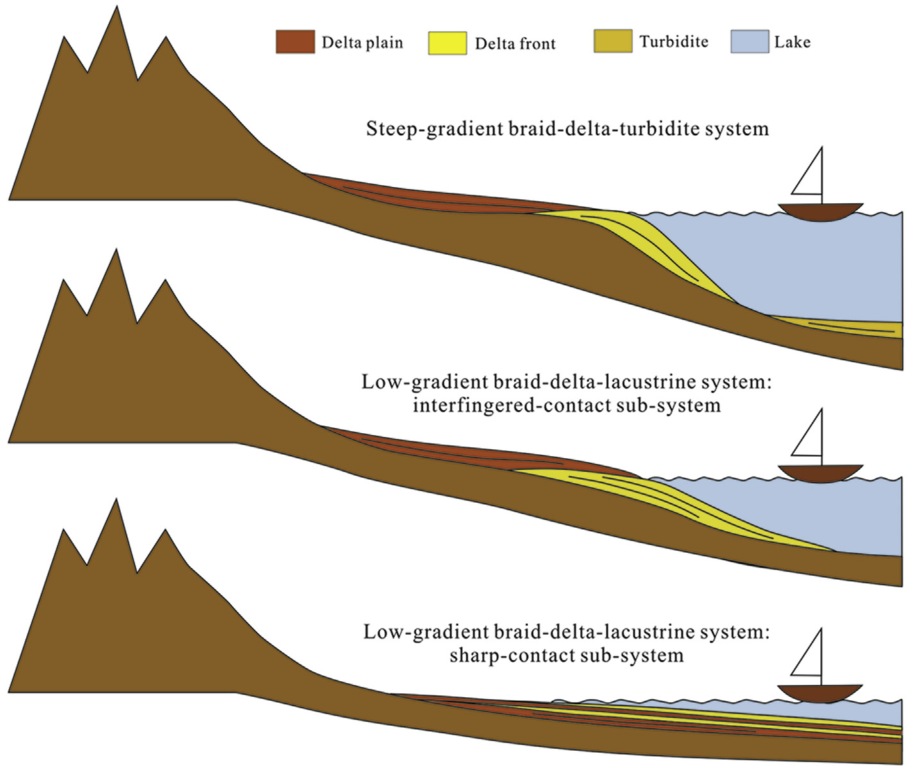

Figure 11. Cartoons of different types of braid-delta depositional systems, associated systems, morphology and relative ramp gradients in basin margins.

steep- and low-gradient braided deltas is whether there is turbidity deposition.

Comparison of the main controlling factors in different styles of braid delta in lacustrine basins indicates that paleotopography, as the most influential forcing parameter, strongly controls the migration of the shoreline and influences the distribution of the accommodation. This paleotopography also governs the sedimentary systems and distribution of reservoirs, which can inform hydrocarbon exploration and development.

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