Lithofacies, Succession, and Their Genetic Interpretation of Lacustrine Gravel Beach-Bars

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Received 20 April 2021; Accepted 5 July 2021; Published 17 August 2021

Academic Editor: Zhongwei Wu

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Based on the elaborate dissection of profile sections parallel and vertical with the shoreline and the forming beach-bars, the unique sedimentary succession of gravel beach-bars, “ABC” sequence, has been found, and their lithofacies and origin have been explained. The A interval is composed of poorly sorted sand and gravel, formed in the wave asymmetric zone. The B interval is composed of well-sorted gravel, formed in the breaker zone. The C interval is composed of normally graded sand, formed in the surfing zone. In the actual gravel beach-bars, three intervals are often presented in a variety of combinations, such as “ABCABC,” “BCBCBC,” “ABABAB,” and others. These findings provide an important basis for the identification and distribution prediction of beach-bar reservoirs in the ancient continental lake basins.

1. Introduction

Lacustrine beach-bar deposits are characterized by well physical property, and it is easy to form large-scale oil and gas fields that is one of the important reservoirs in petrolierous basins in China [1–6]. So far, a considerable number of oil-bearing beach-bar deposits have been discovered in Bohai Bay Basin, Erdos Basin, Junggar Basin, and Pearl River Mouth Basin [7–12].

Beach-bars can be divided into three types, gravel beach-bars, sandy beach-bars, and carbonate beach-bars. But most of researches pay close attention to sandy beach-bars and lose sight of gravel beach-bars. Such as Aagaard (1990), Zhu Xiaomin (1994), Soreghan and Cohen (1996), Deng Hongwen (2011), Schwartz (2012), and Jiang Zaixing (2012) [6, 13–17]. They have made a comprehensive study on the sedimentary characteristics, geophysical characteristics, distributional pattern, and reservoir characteristics of the sandy beach-bars. The gravel beach-bars are often ignored.

Most of the research are based on ancient beach-bar deposits, and the data used are multiple solutions, such as seismic and logging data. Different people can produce different conclusions. So many conclusions may be misinterpreted. In addition, the difficulty of the research of beach-bars lies in how to differentiate between ancient beach-bar deposits and ancient delta-front deposits. The beach-bar deposits and delta-front deposits are similar in a sedimentary environment and hydrodynamic conditions and have similar lithology, sedimentary structure, and texture [1, 15, 18–20]. In ancient layers, it is difficult to distinguish between beach-bar deposits and delta-front deposits. This seriously restricts the paleogeographical reconstruction and hydrocarbon prediction.

In view of the above problems, through the study of modern gravel beach-bars in the Qinghai Lake, the authors summarize sedimentary characteristics, successions, and model of gravel beach-bars and interpret the origin of sedimentary successions of gravel beach-bars. These findings
provide an important basis for the identification and distribution prediction of beach-bars in the ancient continental lake basins.

2. Geological Setting

Qinghai Lake (36°32’ to 37°15’N, 99°36’ to 100°46’E), the largest extant closed-basin lake in China, is situated at an altitude of 3194 m above the sea level on the northeastern Qinghai-Tibetan Plateau. The lake area is surrounded by Datong Mountain, Sun Moon Mountain, and Qinghai South Mountain, which form the closed inland faulted basin. The long axis direction of Qinghai Lake (nearly east-westward) is about 106 km; the transverse direction (near north-southward) is about 63 km; the lake altitude is 3193–3198 m; the surface area is 4264–4473 km²; and the perimeter of the lake is about 360 km. The lake shape is oval, and the east-west direction is longer than the north-south direction. The long axis of the north-west to about 315°. The average depth of the lake is approximately 21 m, its maximum water depth is approximately 32 m, and the water storage reaches 100 × 10⁹ m³ [21] (Figure 1(a)).

In this study, the beach-bar deposits is located at the Erhai on the southeast coast of Qinghai Lake (100°43’54.5”E, 36°33’2.3”N) (Figure 1). The beach-bars formed by the action of longshore currents separate the Erhai from the Qinghai Lake. Therefore, the Erhai became a completely enclosed lagoon (Figure 1(b)). Because the lake level of the Qinghai Lake is currently declining [21], which formed a widely distributed, several rows are parallel to the shoreline and progradational type of beach-bar deposits in the Erhai (Figure 1(b)).

3. Methodology

The modern is the key to the past. Based on the field investigation of the Qinghai Lake, the authors have carried out the elaborate dissection of profile sections parallel and vertical with the shoreline on the southeast Qinghai Lake. The profile section parallel with the shoreline is located at 100°43’23.4”E, 36°32’42.6”N, and the azimuth angle of the section is 49° (the azimuth angle of the shoreline is 51°). The profile section vertical with the shoreline is located at 100°43’23.4”E, 36°32’42.6”N, and the azimuth angle of the section is 315°. Except
for the profile sections, forming beach-bars in the Qinghai Lake had been used to investigate the formation mechanisms of gravel beach-bar sedimentary succession.

4. Large-Scale Sedimentary Characteristics of Gravel Beach-Bars in the Southeastern Qinghai Lake

Several beach-bar deposits are developed parallel to the shoreline on the southeastern Qinghai Lake, and the long axis azimuth angle of the beach-bars is about 43°. The maximum length of the beach-bars is able up to 8 km; the average is about 5 km. The maximum width of the beach-bars is able up to 0.7 km; the average is about 0.3 km. The maximum gravel thickness is more than 6 m. The geometry shape of the beach-bars is long and strip-like with a concave top and flat bottom (Figure 2).

The southeastern beach-bars are mainly composed of medium gravel, fine gravel, and coarse sand. The grains are subround; the sorting is from poor to better, with parallel bedding, flushing cross-bedding, massive bedding, and normal grading bedding.

5. Sedimentary Characteristics of the Profile Parallel with the Shoreline

The profile is about 2 m in height and about 15 m in width (actually the beach-bar is 4800 m in length, 6 m in thickness, and 400 m in width) (Figure 3). From bottom to top, the profile parallel with the shoreline can be divided into 17 layers on the basis of their lithology, texture, sedimentary structure, thickness of layers, lateral continuity, and contact relationship between top and bottom (Figure 4). Because the profile is parallel with the
are the 7th, 9th, 11th, 13th, and 15th, and the mean grain size of each layer is di (medium-sorted to well-sorted) (Figure 4). The mean grain size is between -4 and -1.5 phi, and the sorting is less than 2 (Figures 4(d) and 4(g)). The 5th, 10th, 12th, 14th, and 16th all belong to the B interval (Figure 4).

6. Sedimentary Characteristics of the Profile

Vertical with the Shoreline

The profile is about 2.5 m in height and about 15 m in width (actually the beach bar is 4800 m in length, 6 m in thickness, and 400 m in width) (Figure 5).

The profile vertical with the shoreline is mainly composed of medium gravel, fine gravel, and coarse sand; the whole is a low-angle swash bedding; and each lamina dip is about 4°~6°. The lateral continuity of each lamina is unstable and difficult to track laterally. To better describe the profile sedimentary characteristics, the profile is divided into two lithologic columns: Column 2 and Column 3 (Figures 5 and 6).

From bottom to top, each lithologic column can be divided into several layers on the basis of their lithology, texture, sedimentary structure, thickness of layer, lateral continuity, and contact relationship (Figures 5 and 6). Some of the layers can be tracked laterally. The layers change greatly in thickness, and the overall trend is to reduce toward the lake. The thickness of layers is about 20 cm, the thickest is able up to 60 cm, and the thinnest is able up to 5 cm. Abrupt transitions can be seen between most of the top-bottom interface of each layer. Each layer extends laterally 4 m to the left, the longest can reach 7 m, and the shortest can reach 2 m. The dip angle of each layer to the lacustrine direction is about 4°~6° (Figure 5).

Each layer is composed of medium gravels, fine gravels, and coarse sands, respectively, and the grains are subround. The layers have mainly massive bedding and normally graded bedding. On the basis of the lithology, sedimentary structure, size parameter, thickness, and contact relation between top and bottom of the profile, the layers can be divided into three intervals: A, B, and C (Figure 6).

The A interval is dominated by gravels and sands, which are subround and poorly sorted and have massive bedding with gravels oriented floating in the coarse sands. The thickness is more than 15 cm. The mean grain size is between -2 and -1 phi, and the sorting is more than 2 (Figures 4(d) and 4(e)). The 1st, 3rd, 6th, 8th, and 17th layers all belong to the A interval (Figure 4).

The B interval is dominated by gravels, which are subround and well-sorted and have massive bedding with a thickness of 7 to 15 cm. The mean grain size is between -4 and -1.5 phi, and the sorting is less than 2 (Figures 4(d) and 4(f)). The 2nd, 4th, 7th, 9th, 11th, 13th, and 15th all belong to the B interval (Figure 4).

The C interval is dominated by sands, which are subround and well-sorted and have normal grading bedding; the thickness is less than 9 cm. The mean grain size is between -1 and 0, and the sorting is less than 2 (Figures 4(d) and 4(g)). The 5th, 10th, 12th, 14th, and 16th all belong to the C interval (Figure 4).

Through the analysis of samples from each layer, it is found that 17 layers have two kinds of sorting coefficients. On the basis of sorting, 17 layers can be divided into two parts. One part is more than 2 (poorly sorted), including 1st, 3rd, 6th, 8th, and 17th layers. The other is less than 2 (medium-sorted to well-sorted) (Figure 4). The thickness of 7 to 15 cm. The mean grain size is between -4 and -1.5 phi, and the sorting is less than 2 (Figures 4(d) and 4(g)). The 5th, 10th, 12th, 14th, and 16th all belong to the B interval (Figure 4).

According to the lithology, sedimentary structure, grain-size parameter, thickness, and contact relation of the profile, 17 layers can be divided into three intervals: A, B, and C.

The A interval is dominated by gravels and sands, which are subround and poorly sorted and have massive bedding, with gravels oriented floating in the coarse sands. The thickness is more than 15 cm. The mean grain size is between -2 and -1 phi, and the sorting is more than 2 (Figures 4(d) and 4(e)). The 1st, 3rd, 6th, 8th, and 17th layers all belong to the A interval (Figure 4).

The B interval is dominated by gravels, which are subround and well-sorted and have massive bedding with a thickness of 7 to 15 cm. The mean grain size is between -4 and -1.5 phi, and the sorting is less than 2 (Figures 4(d) and 4(f)). The 2nd, 4th, 7th, 9th, 11th, 13th, and 15th are all belong to the B interval (Figure 4).

The C interval is dominated by sands, which are subround and well-sorted and have normal grading bedding; the thickness is less than 9 cm. The mean grain size is between -1 and 0, and the sorting is less than 2 (Figures 4(d) and 4(g)). The 5th, 10th, 12th, 14th, and 16th all belong to the C interval (Figure 4).
The C interval is dominated by sands, which are subround and well-sorted and have normal graded bedding. The thicknesses are less than 10 cm and from 1 to 3 m in horizontal width (Figure 6).

7. Sedimentary Succession and Genetic Interpretation of Gravel Beach-Bars

Through a detailed study of the profile vertical and parallel with the shoreline, it is found that gravel beach-bars have a fixed sedimentary succession, named “ABC” sequence (Figure 7):

1. The A interval, the bottom of the sedimentary succession, is dominated by coarse sands and gravels, which are subround and poorly sorted and have massive bedding, with gravels oriented floating in the coarse sands

2. The B interval, the middle of the sedimentary succession, is dominated by gravels, which are subround and well-sorted and have massive bedding
The C interval, the top of the sedimentary succession, is dominated by coarse sands, which are well-sorted and have normally graded bedding. In the actual gravel beach-bars, three intervals are often presented in a variety of combinations, such as "ABCABC," "BCBCBC," "ABABAB," and other combinations (Figures 4 and 6).

Through the study of forming beach-bars in the Qinghai Lake, the "ABC" sequence is also found in the surface (Figure 8). The A interval is located in the wave asymmetric zone (the wave shoaling zone called by other researchers; the wave can impact the lake bottom, and the wave height begins to rise but is not broken enough) (Figure 8). The oscillation amplitude and energy of waves are weak so that sands can be transported, but gravels cannot be transported. The authors think that the gravel of the A interval is transported by intermittent storm waves. After the storm, the wave cannot move the gravel of the A interval, so the A interval is poorly sorted and gravels are oriented floating in the coarse sands (Figure 8). The B interval is located in the breaker zone (Figure 8). In this zone, the wave is broken diving into the bottom of the lake. The energy is strongest. The sediments are coarsest, because the relatively fine sediments cannot deposit in this zone. Therefore, the B interval is well-sorted (Figure 8). The C interval is located in the surfing zone (Figure 8). After the wave is broken, most of the energy is consumed. Due to the effect of inertia, the wave continues to move landwards until the energy is exhausted. The sediments deposit orderly form large to small, leading the normal grading in the C interval (Figure 8). Due to the difference of wind, wave, and lake level at each season, even every year, the location of the wave asymmetric zone, the breaker zone, and surfing zone can change back and forth. Therefore, the ABC intervals in the actual beach-bars are displayed in various combinations, such as "ABCABC," "BCBCBC," and "ABABAB."

8. Sedimentary Model of Gravel Beach-Bars in Qinghai Lake

Through the three-dimensional anatomy of the gravel beach-bars on the southeastern part of the Qinghai Lake, including the profile vertical to the shoreline, the profile parallel to the shoreline, and the depositing surface, the sedimentary model of gravel beach-bars was established finally (Figure 9).

The hydrodynamic conditions of the formation of gravel beach-bars can be divided into three zones: the wave asymmetric zone, breaker zone, and surfing zone (Figure 9). Above the wave base, the wave begins to impact the bottom of the lake; the frictional force between the lake bottom and the wave causes the asymmetric deformation of waves; this area is the wave asymmetric zone. The wave is seriously deformed until broken and plunges to the lake bottom; this area is the breaker zone. After the wave is broken, due to the effect of inertia, the water continues to move to the shore until the energy is depleted; the area is the surfing zone.

The sediments of the asymmetric wave zone are mainly sandstone, and the flat gravels are scattered sporadically.
The sediments of the breaker zone are mainly conglomerates and well-sorted. The surfing zone sediments are mainly sandstones and normally grading.

With the rising and falling of the lake level, the three hydrodynamic zones migrate back and forth on the plane, resulting in the sediments of three zones vertical overlaying each other.

9. Ancient Gravel Beach-Bar Identification Mark

In ancient formations, there are many similarities between the beach-bar deposits and the delta-front deposits, which is confusing. Delta-front deposits and beach-bar deposits are mainly developed in the shallow water area of the Qinghai Lake; the beach-bars accounted for about 60%, and the delta-fronts accounted for 40%. In many researches of ancient lacustrine basin deposits, generally, the delta-front deposits occupy the majority. The authors think that many delta-front deposits may be misinterpreted as beach-bar deposits.

Through the detailed study of the modern lacustrine gravel beach-bars, the identification mark of the ancient beach-bars has been supplemented and perfected (Table 1). The specific identification marks are as follows:

(1) The difference in sedimentary succession: the gravel beach-bar deposits have a fixed sedimentary succession, the “ABC” sequence. With the wave size and lake level changes, gravel beach-bar deposits are actually presented in variously combined patterns, such as “ABCABC,” “ABABAB,” and “BCBCBC.”

(2) The difference in sedimentary structures: there is low-angle swash bedding in beach-bar deposits.
There is much parallel bedding in the profile parallel to the shoreline, with flat gravels floating in the sands.

(3) The difference in textures: the textural maturity of the beach-bars is higher, the granules are subround, and the sorting can change from poorly to well.

(4) The difference in top-bottom interface: the bottom interface of the beach-bar deposits is generally a flat abrupt surface.

(5) The difference in geometries: the trend of the beach-bars is parallel to the shoreline, and the geometry shape is long stripe-like with convex tops and flat bottoms.

10. Discussion

These viewpoints of gravel beach-bar deposits developed in the lacustrine basin differ from the previous research of beach-bars [18, 22–25].

Jiang et al. and Hongwen et al. hold that the lacustrine beach-bars are characterized by sandstones interbedded with thin mudstone units and the presence of well-developed sedimentary structures, such as swash bedding, parting
lineation, parallel bedding, ripples, terrestrial plant debris, and vertical burrows [1, 15]. Peng et al. established the physical criteria for the recognition of lacustrine beach-bars, which include many quantitative parameters of beach-bar [23]. Zhu et al. established four depositional models of lacustrine beach-bars, beach-bars in open shallow lake, beach-bars in turning of shoreline, beach-bars beside deltas, and beach-bars in ridges of deep lake [6]. However, both of them neglected the effect of different wave zone to sediments. Although the lake waves are not as big as the sea waves, the effect of different wave zone to sediments is still obvious. Our study shows that the lake waves are obviously divided into three parts, wave asymmetric zone, wave breaker zone, and wave surfing zone (Figure 9). The different wave zones have different sedimentary characteristics (Figures 7 and 8).

At present, no one has proposed the particular depositional succession of lacustrine beach-bars. Most beach-bar researches pay their attention to the summary of lithology, texture, sedimentary structure, distributional pattern [15, 18, 24], or the applied research of lacustrine beach-bars [5, 25, 26]. Through our study on the several beach-bar profiles in the Qinghai Lake, the lacustrine gravel beach-bars are composed several particular depositional successions, the “ABC” succession (Figure 7). The gravel beach-bars can present various combinations: “ABABAB,” “ABCABC,” “BCBCBC,” etc. (Figures 4 and 6).

The sedimentary environment of lacustrine beach-bars is similar to the sedimentary environment of lacustrine delta fronts [27, 28]. It is difficult how to distinguish between lacustrine beach-bar sediments and delta front sediments in ancient basins. Through our study, the particular identification marks have been proposed. In terms of the bottom contact relationship, the beach-bars are distinct, and the delta fronts are gradual. In terms of the depositional succession, the beach-bars have the “ABC” succession and show a fine-coarse-fine succession from bottom to top. The delta fronts have no special succession and show a fine-coarse succession from bottom to top. These new viewpoints are greatly important for the recognition of lacustrine beach-bar.

11. Conclusion

Gravel beach-bars have a fixed sedimentary succession, “ABC” sequence. The A interval, the bottom of the sedimentary succession, is composed of coarse sands and gravels, which are subrounded and poorly sorted and have massive bedding, with gravels oriented floating in the coarse sands; the B interval, the middle of the sedimentary succession, is composed of gravels, which are subrounded and well-sorted and have massive bedding; the C interval, the top of the sedimentary succession, is composed of coarse sands, which are well-sorted and have normally graded bedding. In the actual gravel beach-bars, three intervals are often presented in a variety of combinations, such as “ABCABC,” “BCBCBC,” and “ABABAB.”

The hydrodynamic conditions of gravel beach-bars can be divided into three zones, wave asymmetric zone, breaker zone, and surfing zone. The sediments of the asymmetric wave zone are mainly sandstones, and flat gravels are scattered sporadically, that is, the A interval. The sediments of the breaker zone are mainly conglomerates and well-sorted, that is, the B interval. The surfing zone sediments are mainly sandstones and normally grading, that is, the C interval.

Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Disclosure

This work has been presented as a conference abstract in IOP Conference Series: Earth and Environmental Science Volume 300 Issue 2.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

This work was supported by the Fundamental Research Funds for the Central Universities, CHD (Program No. 300102270505), was supported by the Natural Science Basic Research Program of Shaanxi (Program No. 2020JQ-1002), and was funded by the Technology Innovation Center for Land Engineering and Human Settlements, Shaanxi Land Engineering Construction Group Co., Ltd., and Xi’an Jiaotong University (Program No. 2021WHZ0090).

References

[1] Z. Jiang, S. Liang, Y. Zhang, S. Zhang, L. Qin, and X. Wei, “Sedimentary hydrodynamic study of sand bodies in the upper subsection of the 4th member of the Paleogene Shahejie Formation the eastern Dongying Depression, China,” Petroleum Science, vol. 11, no. 2, pp. 189–199, 2014.
[2] B. J. Liu, “Environmental analysis of terrestrial sources marine strata,” Geological Bulletin, vol. 1, no. 1, pp. 32–43, 1982.
[3] C. J. Wu, “Sandbodies in Lake Basin,” Acta Sedimentologica Sinica, vol. 4, no. 4, pp. 1–27, 1986.
[4] Y. Q. Yang, L. W. Qiu, Z. X. Jiang, and X. L. Yin, “A depositional pattern of beach bar in continental rift lake basins: a case study on the upper part of the fourth member of the Shahejie Formation in the Dongying Sag,” Acta Petrolei Sinica, vol. 32, no. 3, pp. 417–423, 2011.
[5] D. N. Zhao, X. M. Zhu, Y. L. Dong, D. Wu, and M. Zhu, “Application of seismic sedimentology to prediction of beach and bar sandbodies in gentle slope of lacustrine basin: a case study of the Lower Cretaceous in Chepaizi area, Junggar Basin, NW China,” Petroleum Exploration and Development, vol. 40, no. 1, pp. 55–61, 2014.
[6] X. M. Zhu, Q. L. Xin, and J. R. Zhang, “Sedimentary characteristics and models of the beach-bar reservoirs in faulted down lacustrine basins,” Acta Sedimentologica Sinica, vol. 12, no. 2, pp. 20–28, 1994.
[7] Y. L. Ji, H. Lu, and Y. R. Liu, “Sedimentary model of shallow water delta and beach bar in the member 1 of Paleogene Funing Formation in Gaoyou sag, Sabei Basin,” Journal of Palaeogeography, vol. 15, no. 5, pp. 729–740, 2013.
Y. S. Wang, H. M. Liu, Y. J. Gao, M. R. Tian, and D. Tang, "X. B. Wu, J. G. Hou, D. X. Wang et al., "X. Y. Yang, Z. G. Shen, S. X. Fang et al., "T. Aagaard, "M. J. Soreghan and A. S. Cohen, "D. Hongwen, X. Yi, M. Lixiang, and J. Zhenglong, "R. K. Schwartz, "Q. H. Liu, H. T. Zhu, Y. Shu, X. M. Zhu, X. H. Yang, and X. Fu, "Provenance systems and their control on the beach-bar of Paleogene Enping Formation, Enping sag, Pearl River Mouth Basin," Acta Petrolei Sinica, vol. 36, no. 3, pp. 286–299, 2015.

X. F. Shang, "Architectural characteristics and sedimentary models of beach-bars sandstone reservoirs: a case study of the Paleogene Shahejie Formation in Banqiao oilfield, Huanghua depression," Acta Petrolei Sinica, vol. 35, 2014.

Y. S. Wang, H. M. Liu, Y. J. Gao, M. R. Tian, and D. Tang, "Sandbody genesis and hydrocarbon accumulation mechanism of beach-bar reservoir in faulted-lacustrine-basins: a case study from the upper of the fourth member of Shahejie Formation, Dongying Sag," Earth Science Frontiers, vol. 19, no. 1, pp. 100–107, 2012.

X. B. Wu, J. G. Hou, D. X. Wang et al., "Study on sedimentary microfacies of beach-bar sand of the first member of Shahejie Formation in Guangzhong Oilfield based on the modern Qinghai Lake deposition," Journal of Xian Shiyou University(Natural Science Edition), vol. 28, no. 5, pp. 31–38, 2013.

X. Y. Yang, Z. G. Shen, S. X. Fang et al., "Sedimentary characteristics of beach and bar sandbodies in the lower submember of member 8 of Xiashihazi Formation of Middle Permian in Wushengqi Gasfield Ordos Basin," Journal of Palaeogeography, vol. 9, no. 2, pp. 175–183, 2007.

T. Aagaard, "Infragravity waves and nearshore bars in protected, storm-dominated coastal environments," Marine Geology, vol. 94, no. 3, pp. 181–203, 1990.

M. J. Soreghan and A. S. Cohen, "Textural and compositional variability across littoral segments of Lake Tanganyika: the effect of asymmetric basin structure on sedimentation in large rift lakes," AAPG Bulletin, vol. 80, no. 3, pp. 382–408, 1996.

D. Hongwen, X. Yi, M. Lixiang, and J. Zhenglou, "Genetic type, distribution patterns and controlling factors of beach and bars in the second member of the Shahejie formation in the Dawangbei Sag, Bohai Bay, China," Geological Journal, vol. 46, no. 4, pp. 380–389, 2011.

R. K. Schwartz, "Bedform, texture, and longshore bar development in response to combined storm wave and current dynamics in a nearshore helical flow system," Journal of Coastal Research, vol. 28, no. 6, pp. 1512–1535, 2012.

Z. X. Jiang, J. R. Wang, and Y. F. Zhang, "Advance in beach-bar research: a review," Journal of Palaeogeography, vol. 17, no. 4, pp. 427–440, 2015.

Z. Jiang, H. Liu, S. Zhang, X. Su, and Z. Jiang, "Sedimentary characteristics of large-scale lacustrine beach-bars and their formation in the Eocene Boxing Sag of Bohai Bay Basin, East China," Sedimentology, vol. 58, no. 5, pp. 1087–1112, 2011.

Y. L. Ji, J. L. Liu, T. Y. Wang, D. W. Liu, and T. R. Cheng, "Distributing pattern and mapping method of delta and beach-bar composite sandbodies in continental lacustrine basin," Journal of Palaeogeography, vol. 18, no. 4, pp. 615–630, 2016.

Z. Z. Feng, sedimentary petrology, Petroleum Industry Press, 1993.

LZBCS, Evolution of recent environment in Qinghai Lake and its prediction, science press, Beijing, 1994.

A. Luijendijk, G. Hagenaaars, R. Ranaasinghe, F. Baart, G. Donchyts, and S. Aarninkhof, "The State of the World's Beaches," Scientific Reports, vol. 8, no. 1, p. 6641, 2018.