Sedimentary Succession and Model of Gravel Beach-Bars in The Southeastern Qinghai Lake

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Abstract. 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 profiles parallelly and vertically with the shoreline and the surface analysis of the forming beach-bars. The sedimentary successions of gravel beach-bars are summarized and the model of gravel beach-bars are established. The gravel beach-bars have a fixed sedimentary succession, the "ABC" sequence. A interval, the bottom of the sedimentary succession, is composed of coarse sands and gravels, which are sub-rounded, poorly-sorted, massive, and gravels oriented floating in the coarse sands; B interval, the middle of the sedimentary succession, is composed of gravels, which are sub-round, well-sorted, and massive bedding; C interval, the top of the sedimentary succession, is composed of coarse sands, which are well-sorted and 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. The hydrodynamic conditions of gravel beach-bars can be divided into three zone, wave asymmetric zone, breaker zone and surfing zone. The three zones respectively correspond with the A interval, B interval, and C interval. These findings provide an important basis for the reconstruction of paleoenvironment and the identification and distribution prediction of beach-bars 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 petroliferous basins in China (Jiang et al, 2015, Liu, 1982, Wu, 1986, Yang et al, 2011, Zhao et al., 2014; Zhu et al, 1994). 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 [1-3].
Beach-bars can be divided into three types, gravel beach-bars, sandy beach-bars, and carbonate beach-bars. But most of the research 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), Jing Jinhua (1998), Song Chunhui (1999), Chen Shiyou (2000), Houser and Greenwood (2005), Deng Hongwen (2009), Schwartz (2010), Schwartz (2012), Tian Jiun (2012), the Jang Zaixing (2012), etc. They have made a comprehensive study on the sedimentary characteristics, geophysical characteristics, distributional pattern and reservoir characteristics of the sandy beach-bars [4-8].

Most of the research are based on ancient beach-bars 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 sedimentary environment and hydrodynamic conditions, and have similar lithology, sedimentary structure and textual [9-10]. 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 reconstruction of paleoenvironment and the identification and distribution prediction of beach-bars in the ancient continental lake basins.

2. Another section of your paper

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 3194m 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 forms the closed inland faulted basin. The long axis direction of Qinghai Lake (nearly east-westward) is about 106km; the transverse direction (near north-southward) is about 63km; the lake altitude is 3193–3198m; the surface area is 4264–4473km2 and the perimeter of the lake is about 360km. The lake shape is oval, and the east-west direction is longer than north-south direction. The long axis of the north-west to about 315°. The average depth of the lake is approximately 21m, it’s the maximum water depth is approximately 32m, and the water storage reaches 100×109 m3 [4] (Figure 1A).

In this study, the beach-bar deposits are 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 1B). Because the lake level of the Qinghai Lake is currently declining [4], which formed a widely distributed, several rows parallel to the shoreline and progradational type of beach-bar deposits in the Erhai (Figure 1B).

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 parallelly and vertically with the shoreline on the southeast Qinghai Lake. The profile section parallelly with the shoreline is located at 100°43′ 23.4″E, 36°32′ 42.6″N, the azimuth angle of the section is 49° (the azimuth angle of the shoreline is 51°). The profile section vertically with the shoreline is located at 100°43′23.4″E, 36°32′42.6″N, the azimuth angle of the section is 315°. Except for the profile sections, a 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 parallelly 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 8km; the average is about 5km. The maximum width of the beach-bars is able up to 0.7km; the average is about 0.3km. The maximum gravel thickness is more than 6m. The geometry shape of the beach-bars is long strip-like with concave top and flat bottom (Figure 1B). The southeastern beach-bars are mainly composed of medium gravel, fine gravel and coarse sand. The grains are sub-round, the sorting is from poor to better, and with parallel bedding, flushing cross-bedding, massive bedding, and normal grading bedding.

5. Sedimentary characteristics of the profile parallelly with the shoreline
The profile is about 2m in height, and about 15m in width (actually the beach-bar is 4800m in length, 6m in thickness, 400m in width) (Figure 2).

From bottom to top, the profile parallelly 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 3). Because the profile is parallel with the shoreline, the dip angle of layers is almost 0°, and the transverse continuity is well, and it is easy to track laterally (Figure 2 and 3). The abrupt transition can be seen in most of layers. The transitions are
gradual just between the 4th and 5th layers, between the 9th and 10th layers, between the 11th and
12th layers, between the 13th and 14th layers, and the 15th and 16th layers. The thickness of 17
layers are mostly about 10cm, that the thickest 1th and 6th layers can be more than 20cm, and the thinnest
4th, 5th and 16th layers are lower than 5cm. The layers are mainly composed of medium gravel, fine
gravel and coarse sand, and the massive bedding and the normal grading bedding are very developed.
The massive bedding is only 5th, 12th, 14th and 16th layers. In the 1st, 3th, 6th, 8th and 17th layers,
gravels are oriented and floating in the coarse sands. (Figure 3).

Through the analysis of samples from each layer, it is found that 17 layers have two kinds of
sorting coefficients. On basis of sorting, 17 layers can be divided into two parts. One part is more than
2 (poorly-sorted), including 1th, 3th, 6th, 8th and 17th layers. Others are less than 2 (medium-sorted to
well-sorted) (Figure 3). The mean grain size of each layer is different. The coarse grain size layers are
7th, 9th, 11th, 13th and 15th, and the mean grain size is lower than -2.5phi. The fine grain size layers
are 1th, 5th, 8th and 12th, and the mean grain size is more than -1phi (Figure 3).

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.

An interval is dominated by gravel and sand, which are sub-rounded, poorly-sorted, massive bedding,
and gravels oriented floating in the coarse sands. The thickness is more than 15cm. The mean grain
size is between -2 and -1 phi, and the sorting is more than 2. The 1th, 3th, 6th, 8th and 17th layers are
all belong to the A interval (Figure 3).

B interval is dominated by gravel, which are sub-rounded, well-sorted, massive bedding, and 7 to
15cm in thickness. The mean grain size is between -4 and -1.5 phi, and the sorting is less than 2. The
2th, 4th, 7th, 9th, 11th, 13th and 15th are all belong to the B interval (Figure 3).

C interval is dominated by sand, which are the sub-rounded, well-sorted, normal grading bedding,
the thickness is less than 9cm. The mean grain size is between -1 and 0, and the sorting is less than 2.
The 5th, 10th, 12th, 14th and 16th are all belong the C interval (Figure 3).

Figure 2. Profile of gravel beach-bars in the southeastern Qinghai Lake paralleled with the shoreline.

6. Sedimentary characteristics of the profile vertically with the shoreline

The profile is about 2.5m in height, and about 15m in width (actually the beach bar is 4800m in length,
6m in thickness, 400m in width) (Figure 4).

The profile vertically with the shoreline is mainly composed of medium gravel, fine gravel and
coarse sand, the whole is a low-angle swash bedding, and each laminae dip is about 4–6°. The lateral
continuity of each laminae is unstable and difficult to track laterally. To better describe the profile
sedimentary characteristics, the profile is divided into two lithologic columns: Column 1 and Column
2 (Figure 4 and 5).

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
(Figure 4 and 5). Some of 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 are about 20cm, the thickest is
able up to 60cm, the thinnest is able up to 5cm. Abrupt transitions can be seen between most of the
top-bottom interface of each layer. Each layer extend laterally are 4m to the left, the longest can reach
7m, the shortest can reach 2m. The dip angle of each layer to the lacustrine direction is about 4–6°
(Figure 4).
Figure 3. Photography, sketch, and grain-size data of profile section of gravel beach-bars in the southeastern Qinghai Lake paralleled with the shoreline.

Each layer is composed of medium gravels, fine gravels and coarse sands respectively, and the grains are sub-rounded. The layers are mainly massive bedding and normally graded bedding. On 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 5).

An interval is dominated by gravel and sand, which are sub-round, poorly-sorted, massive bedding, and gravels oriented floating in the coarse sands. The thickness from 5 to 60 cm, and from 3 to 6 m in lateral width (Figure 5).

B interval is dominated by gravel, which are sub-round, well-sorted, and massive bedding. The thickness from 5 to 40 cm, and from 2 to 7 m in horizontal width (Figure 5).

C interval is dominated by sand, which are sub-rounded, well-sorted, and normal graded bedding. The thickness is less than 10 cm, and from 1 to 3 m in horizontal width (Figure 5).
7. Sedimentary succession and genetic interpretation of Gravel Beach-bars

Through detailed study of the profile vertically and parallelly with the shoreline, it is found that gravel beach-bars have a fixed sedimentary succession, named "ABC" sequence (Figure 6):

An interval, the bottom of the sedimentary succession, is dominated by coarse sands and gravels, which are sub-rounded, poorly-sorted, massive, and gravels oriented floating in the coarse sands;

B interval, the middle of the sedimentary succession, is dominated by gravels, which are sub-rounded, well-sorted, and massive bedding;

C interval, the top of the sedimentary succession, is dominated by coarse sands, which are well-sorted and 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 (Figure 3 and 5).
Figure 6. Sedimentary succession of gravel beach-bars.

Through the study of forming beach-bars in the Qinghai Lake, the "ABC" sequence is also found in the surface (Figure 7). The A interval is located in the wave asymmetric zone (the wave shoaling zone called by other researchers, that the wave can impact the lake bottom, and the wave height begin rise, but is not broken enough) (Figure 7). The oscillation amplitude and energy of waves is weak so that sands can be transported, and so that gravel 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 that the A interval is poorly-sorted and gravels oriented floating in the coarse sands (Figure 7). The B interval is located in the breaker zone (Figure 7). 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 7). The C interval is located in the surfing zone (Figure 7). 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 7). 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 display in various combination, such as "ABCABC", "BCBCBC ", " ABABAB "and so on.

Figure 7. Photography and sketch of the forming gravel beach-bars in the southeastern Qinghai Lake.

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 vertically the shoreline, the profile parallelly the shoreline and the depositing surface. The sedimentary model of gravel beach-bars was established finally (Figure 8).
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 8). 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 wave asymmetric zone. The wave is seriously deformed until broken, and plunge 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 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 conglomerating 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 zone migrate back and forth on the plane, resulting in the sediments of three zones vertically overlay each other.

9. Conclusion
Gravel beach-bars have a fixed sedimentary succession, "ABC" sequence. A interval, the bottom of the sedimentary succession, is composed of coarse sands and gravels, which are sub-rounded, poorly-sorted, massive, and gravels oriented floating in the coarse sands; B interval, the middle of the sedimentary succession, is composed of gravels, which are sub-round, well-sorted, and massive bedding; C interval, the top of the sedimentary succession, is composed of coarse sands, which are well-sorted and 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.

The hydrodynamic conditions of gravel beach-bars can be divided into three zone, 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 interval A. The sediments of the breaker zone are mainly conglomerating and well-sorted, that is the interval B. The surfing zone sediments are mainly sandstones and normally grading, that is the interval C.

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