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Stratigraphic Development and Sedimentary Environment Evolution in the Bohai Sea Since the Late Pleistocene

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Abstract

In recent years, there have been controversies in the evolution of sedimentary environment and stratigraphic division in the Bohai Sea since the Late Pleistocene. Based on the data (lithology, sedimentary structure, micro-paleontology, and dating data) of 5 boreholes (core of BT113, BT114, BQ1, YRD–1101, and Lz908) in the Bohai Sea, the stratigraphic development and sedimentary environment evolution were revealed in the area since the Late Pleistocene: a marine bed of each borehole in study area was developed during MIS 5 (the MIS 5 bed of core BQ1 is not exposed); during MIS 4, there were fluvial deposits in the cores of BT113, BT114 and BQ1of the study area, but showed be a transitional sedimentary face in cores of YRD–1101 and Lz908,which may be due to the fact that the sea water has not completely withdrawn from the Bohai Sea with short time and temperature decline less than that of the Last Glacial Age. In the early MIS 3, a transgression has been occurred in cores of Lz908, YRD–1101, and BQ1 of the study area, but a fluvial deposit in cores of BT113 and BT114; from the middle and late MIS 3 to the Last Glacial Maximum, the study area was showed a regression during this period; there was have a marine bed due to wide transgression during the Holocene. According to the stratigraphic records of each borehole in the study area, we find that the evolution of the sedimentary environment is consistent with the trend of global sea level changes, indicating that stratigraphic development and the evolution of the sedimentary environment are mainly controlled by global sea level changes in the study area since the Late Pleistocene. In addition, we need further study to find out other factors.

Keywords

Bohai Sea; Late Pleistocene; Sedimentary environment; Sea level.

1. INTRODUCTION

Under the background of the alternation of Quaternary glacial and interglacial periods, a large amount of environmental information has been recorded in sediments of coastal areas with frequent global sea level changes. Since the late Pleistocene, there were sea-land beds by Dramatical changes of sea level in Bohai Sea that a part of the eastern coastal zone of my country. Through a large number of drilling data, the predecessors found that it has experienced 3 large-scale sea-land succession since the Late Pleistocene (Zhao, 1978; Yan, 2006; Liu, 2009; Xu, 2011), corresponding to the Holocene, MIS 3 and MIS 5. Although the recent development in Optical Stimulated Luminescence (OSL) has led to great improvement in the precision of chronology, the environmental evolutions and division of sedimentary strata in the Bohai Sea have been open to debate since the late Pleistocene. Chen Yongsheng (Chen, 2012) and Li Shoujun (Li, 2017) found that the second marine bed belongs to MIS 5 and the third marine layer belongs to MIS 7 basing on cores of BT114 and BT113 on the west coast of the Bohai Sea

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and of GK138, GK111 and GK95 in the Laizhou Bay, respectively. Also baseing on the OSL dating, Yi et al. (Yi, 2015) believe that the second marine bed of core Lz908 in the southern part of Laizhou Bay belongs to MIS 3~5. there are the main reasons that the limitation of dating data and the possible incompleteness of the sedimentary strata to exist a controversy over whether there was develops a marine deposit during MIS 3 in the Bohai Sea area. In response to the above problems, baseing on the data of five boreholes in the Bohai Sea, this study reveals the development of the strata and the evolution of the sedimentary environment to discuss the factors that controlling them since the Late Pleistocene in this area.

2. GEOLOGY OF STUDY AREA

The Bohai Sea is a shallow sea deep inland, with an average water depth of 18 m. The entire bottom of the sea is relatively flat. It mainly accepts sediment from rivers such as the Yellow River, Haihe River, Liaohe River and Luanhe River. Among them, as the river with the highest sediment content in the world, the Yellow River has an average annual runoff of 31.6×109 m3/a, and an average annual sediment transport volume of 7.68×108 t/a, accounting for about 90% of the input of the Bohai River (Saito, 2001). The Bohai Bay Basin is a Meso-Cenozoic faulted basin developed in the northeastern part of North China (Wu, 2000). There are three main groups of NEE, NNE, and Neogene that have developed since the Yanshanian Period. Inheritance extensional faults control the occurrence, development, deposition, and subsidence processes of uplifts or depressions in the Bohai Bay Basin (Gong, 2008; Gao, 2006; Liu, 2019). These major fault boundaries connect the entire Bohai Bay Basin. It is divided into 6 large depression areas in Jizhong, Huanghua, Linqing-Dongpu, Jiyang, Bozhong, and Liaohe, and 3 large uplift areas in Cangxian, Chengning and Neihuang (Liu, 2019) (Figure 1) .

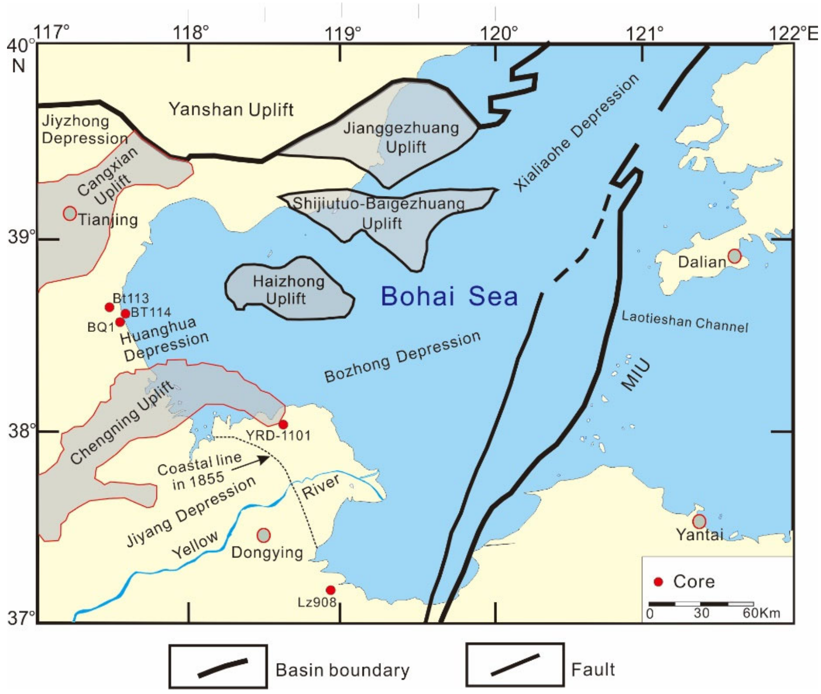

Figure 1. Map showing the core sites and tectonic divisions of the Bohai Basin (modified according to literature

The Miaodao Archipelago is the necessary channel for the exchange of seawater between the Bohai Sea and the Yellow Sea and the Yellow River, Luan River and other rivers entering the Bohai Sea to spread the sediment to the sea (Liu, 2018; Liu, 2008). It divides the Bohai Strait into several water channels, the larger of which is There are 6 waterways in China (Xu, 1997). The overall characteristics of the waterways are wide and deep in the north and narrow and

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shallow in the south (Jiang, 2019). The Laotieshan waterway is the deepest point in the Bohai Sea, with a water depth of 45.0-86.0 m. The seabed of the waterway is the main channel for tidal currents between the Yellow Sea and the Bohai Sea (Guan, 1964).

3. THE STRATIGRAPHIC DEVELOPMENT AND SEDIMENTARY ENVIRONMENT EVOLUTION OF FIVE BOREHOLES IN THE STUDY AREA

3.1. Stratigraphic Development and Sedimentary Environment Evolution of Core BT113

core BT113 is located between the Gaoshaling Uplift and the Upper Gulin Uplift in the secondary structural unit of the Huanghua Depression, with an elevation of 1.44 m (Chen, 2012). According to the analysis of the lithology and biological assemblage of core BT113, combining with the AMS14 C and OSL dating results, the stratum of core can be divided into two marine beds from bottom to top since the Late Pleistocene (Figure 2).

The second marine bed has a depth of 30.2~36.7m, and the bottom is about 2m thick brown-gray fine sand. Most of the mollusc fossils in this layer are incomplete fragments, mainly sea urchin crust and spines. There are a large number of foraminifera, about 400~2500, and the content of three dominant species, Quinqueloculina akneriana, Elphidium.magellanicum and Pseudorotalia gaimardii reaches 80%. In general, the stratum is a coastal shallow sea environment in MIS5.

The first marine bed has a buried depth of 0.8~16.7 m. The upper part is buried at a depth of 0.8~10 m, mainly composed of interbedded black brown clayey silt and yellow-brown silt fine sand. There are a large number of foraminifera in this layer, the number is about 700~3000, and the highest is 5423. The lower part is 10~16.7 m, mainly brown-grey clayey silt, with lenticular bedding. There are a large number of insects, about 640~2 600, and the highest number is 4 568. They are characterized by the combination of A.confertitesta, A.beccarii vars. and A.annectens. Based on the above analysis, it is inferred that this marine bed is a nearshore shallow sea environment in MIS1.

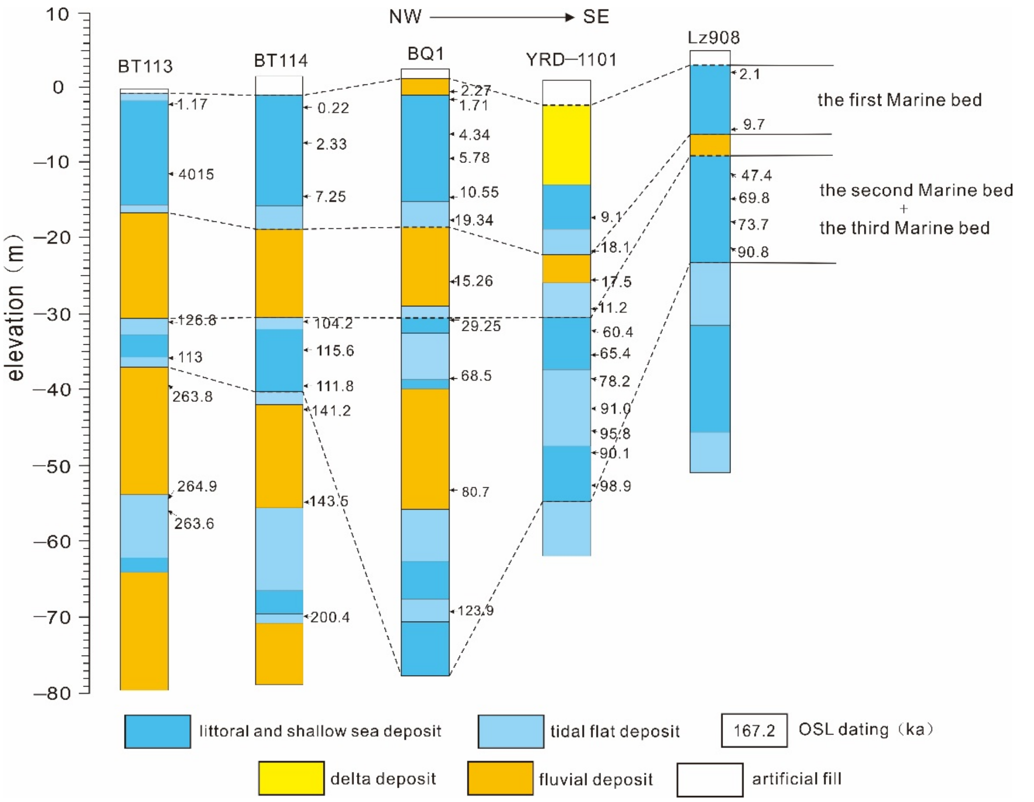

Figure 1. Stratigraphic sequence correlation of cores in the west coast of Bohai Sea

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3.2. Strata Development and Sedimentary Environment Evolution of Core BT114

Core BT114 is located in the Qikou depression of the secondary structural unit in the Huanghua Depression, with an elevation of 2.26 m (Chen, 2012). Based on the analysis of the lithology, sedimentary structure, and biological assemblage of the drill core, combined with the AMS14 C and OSL dating results, the stratum of the core can also be divided into two marine beds from bottom to top since the Late Pleistocene.

The second marine bed with buried depth of 32~43 m, yellowish gray to yellowish brown clay silt, average particle size 5~7 Φ. Sandy thin layer and lens body are interposed in the layer, which is wavy and lens layer The sand body contains shell fragments and well-developed wormholes, indicating a shallow sea environment, corresponding to the MIS 5.

The first marine bed with a buried depth of 2.7~18.9 m is mainly brownish gray to yellow-gray clayey silt, with an average particle size of 5~8 Φ and the grain size gradually becomes coarser when the buried depth is more than 5 m, indicating that the water body is from shallow to Deep-shallow change process. Main lens bedding, rich in shell debris and charcoal, with well developed wormholes, indicating a shallow sea environment, corresponding to the MIS1.

3.3. Stratigraphic Development and Sedimentary Environment Evolution of Core BQ1

The core BQ1 is located in the Dagang District of Tianjin City, about 6 km north of Qikou Town, with an elevation of +3.404 m and a cumulative core length of 7 2.12 m (Yan, 2006). Using basic data such as lithology, paleontology (foraminifers, ostracods and molluscs), dating (OSL and AMS 14C), and paleomagnetism of the borehole, the stratigraphic and sedimentary environment of the core can be Divided into 4 depositional units since the Late Pleistocene.

The fourth sedimentary unit with a burial depth of 56 to 46m is mainly fine silt, with multiple discontinuous surfaces, alternating denudation and redeposition environments. It is deposited in channel, floodplain and shallow lake facies, formed in MIS 4.

The third sedimentary unit with buried at a depth of 31.44~42.18 m is dominated by silty clay, contains marine fossils, and some layers are mixed with freshwater molecules, see gypsum crystal grains and calcareous groups, and determine the marine-land transitional facies of the strata ~Marine muddy sedimentary environment. Optical luminescence dating results show that the formation was formed in MIS 3.

The second sedimentary unit with a burial depth of 31.44-20.45 is dominated by fine sand to medium sand, brown–yellow, containing freshwater biofossils. It is a deposit of riverbed sand and is a typical continental layer formed in MIS 2.

The first sedimentary unit with a burial depth of 20.45~1.70 is dominated by silty silt, black brown, and contains marine fossil components. It is a littoral-neritic environment. The upper layer contains shell debris, carbon debris, gypsum grains and The calcareous group is a marsh salt environment. According to dating data, the formation was formed in the Holocene.

3.4. Stratigraphic Development and Sedimentary Environment Evolution of Core YRD-1101

core YRD–1101 is located near the mouth of the Diaokou Liulu in the northern part of the modern Yellow River Delta, with an elevation of about +1.84 m and a core length of 200.3 m (Liu, 2016). According to optical luminescence, AMS14C dating and stratigraphic comparison studies, the strata above 55.62 m in this hole correspond to the sedimentary environment and can be divided into 3 sedimentary units (DU 3~DU 1) from bottom to top since the Late Pleistocene.

The DU 3 bed (burial depth 19.69 ~ 55.62 m) is MIS5 to early Holocene alternate deposition of river and marine facies, composed of dark yellow, gray–green clay silt, silt, and fine sand. See horizontal bedding and cross bedding. This layer of foraminifera and ostracods consists of two layers of A and B. Phase A is dominated by broad salt to saline water species and coastal species

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(A. beccarii vars., E. magellanicum, P. tuberculatum and C. subincertum), indicating the tidal flat coastal environment; Phase B does not contain deep-water foraminifera, but contains terrestrial and broad-salt ostracods, indicating a river sedimentary environment;

The DU 2 bed (burial depth 13.85~19.69 m) is a Holocene sediment, dominated by dark gray and brownish yellow clayey silt, with brown rust spots in the middle and lower parts, and shell fragments. This layer of foraminifera and ostracods are mainly shallow water species (A. beccarii vars., E. magellanicum, P. tuberculatum and C. subincertum), which are common genera and species in the modern Bohai Sea and shallow seas, indicating that this unit is Normal shallow marine environment;

The DU 1 bed (burial depth 3.36~13.85 m) is the Yellow River delta deposit formed since 1855. It is composed of gray–yellow clay silt and yellow–gray silt interbedded with clear horizontal bedding. The number of foraminifera and ostracods in this bed is relatively small and the species is relatively simple, mainly nearshore shallow water species (A. beccarii vars., P. tuberculatum, and E. magellanicum).

3.5. Stratigraphic Development and Sedimentary Environment Evolution of Core LZ908

Core Z908 is located on the south bank of Laizhou Bay in Bohai Sea, with a hole length of 101.3 m (Yao, 2014). According to the analysis of the lithology and biological assemblage of the drill core, combined with the AMS14 C and OSL dating results, the strata of the drill hole since the Late Pleistocene can be divided into 3 sedimentary units from bottom to top.

The third deposition unit has a buried depth of 16.2-32.4 m. Among them, from 16.2 to 20.6 m from bottom to top, brown clay silt and gray brown silt clay are the main ones. Benthic foraminifera takes Ammonia tepida, Elphidium advenum, Ammonia confertitesta, etc. as the main molecules, showing normal shallow marine environment. Grey–brown and yellow-brown silt is deposited in 20.6~28.4 m, containing a lot of shell fragments. Benthic foraminifers take Elphidium advenum, Ammonia becarii, etc. as the main molecules, indicating the shallow coastal environment. The deposition unit is formed in MIS 5~MIS 3.

The second sedimentary unit with a buried depth of 16.2~11.3 m deposited yellow–brown fine sand, containing calcareous nodules, and basically no foraminifer fossils, indicating a river sedimentary environment, formed in MIS 2.

The first sedimentary unit has a buried depth of 11.3~2.3 m. Among them, the content of Protelphidium granosum is the highest in the foraminifera combination of 2.3~9.5 m. In addition, the shallow water species Quinqueloculina akneriana has the highest content in this section. Therefore, the sedimentary environment of this layer should be subtidal zone and nearshore shallow sea area. From 9.5 m to 11.3 m, Stomoloculina multangula is a typical brackish water indicator in the foraminifera assemblage, and Stomoloculina multangula, Pseudononionella variabilis, and Pseudoeponides anderseni are the representative species of the coastal assemblage. Based on comprehensive analysis, this sedimentary unit should be an intertidal zone-subtidal zone sedimentary environment in MIS 1.

4. RELATIONSHIP BETWEEN STRATIGRAPHIC DIVISION AND SEA LEVEL CHANGE IN THE STUDY AREA SINCE LATE PLEISTOCENE

Chappell (Chappell, 1996) proved that the global sea level is at a high sea level during MIS 5 by coral reef terraces formed around the world. About 120 ka ago, there was a highest value about the global sea level, which is 2~3m higher than the current sea level to form a large-scale transgression (Figure 3). A marine bed has been revealed in boreholes in the study area, which is highly consistent with global sea level changes.

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The global climate gradually became colder and the global sea level dropped to -90~-60 m during MIS 4 ,which was dominated by continental deposits that found in cores of BZ1, BT113, BT114 and BQ1and Lz908 in Bohai Sea,but showed be a transitional sedimentary face in cores of YRD 1101 and Lz908,which may be due to the fact that the sea water has not completely withdrawn from the Bohai Sea with short time and temperature decline less than that of the Last Glacial Age. Also basing on the data of Chappel (Chappell, 1996), we believe that the global sea level has been showing a downward trend that from about – 50 m in the early MIS 3 to about –80 m in the late MIS 3. In recent decades, there has been a new understanding about this problem. For example, some experts believe that the sea level can reach–20~–30 m during MIS 3 in the eastern coastal area of my country (Liu, 2010; Shang, 2018), Which were widely reported in other parts of the world (Cann, 2000; Hanebuth, 2006). Using the research results of the Bohai Basin with a deposition rate of 0.12~0.50 m/ka (Guo, 2007) in the past 6 Ma, we speculate that the Miaodao Archipelago has subsided up to 30 m since the early period of MIS 3 (about 60 ka). The depth of the largest waterway between the islands of the Miaodao Islands is still below–50 m (Liu, 2018),which seawater can enter the Bohai Sea along the deep waterway between the Miaodao Islands to form a certain scale of transgression in the Bohai Sea. The transgression was revealed in cores of Lz908, YRD–1101and BQ1, but a fluvial deposit was formed in cores of BT113 and BT114

From the mid-late MIS 3 to the early Holocene (~10 ka), the global sea level dropped below–80 m.During the Last Glacial Peak (LGM, ~26.5 to 19~20 ka), the global sea level was even lower than the current sea level 120 m with the climate that was cold and dry during this period (Sun, 1992). The strata were exposed to the sea surface for a long time in the form of river environment, which was found in all the boreholes in the study area, indicating that the regression was widespread in the Bohai Sea.

The sea level gradually increased in the post-glacial period until the seawater invaded the Bohai Sea at ~10.5 ka BP, and then the sea level rose gradually, reaching the maximum transgression surface at 7~6 ka BP. This transgression occurred in a large area and was revealed by drilling holes in the study area, which formed tidal flat –coastal environment, coastal marsh–shallow water shelf environment and normal shallow sea environment, respectively. According to the above analysis, we know that the stratigraphic development and sedimentary environment evolution are mainly controlled by the global sea level in the study area since the Late Pleistocene.

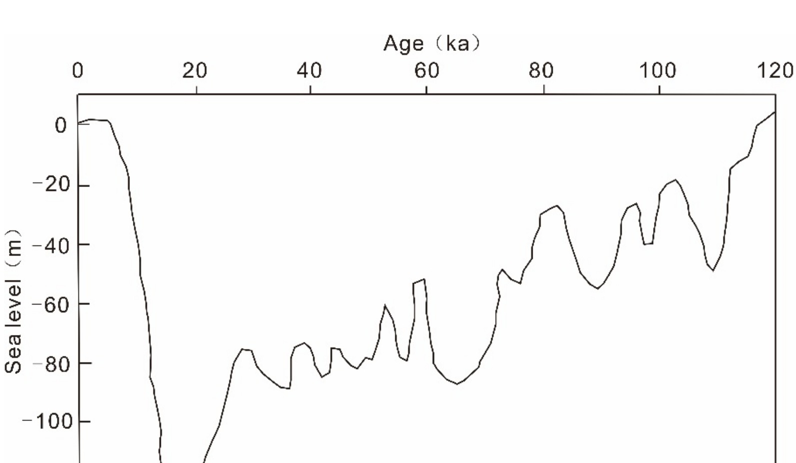

Figure 3. global sea level change curve

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5. CONCLUSIONS

(1) During MIS 4, there were fluvial deposits in the cores of BT113, BT114 and BQ1of the study area, but showed be a transitional sedimentary face in cores of YRD 1101 and Lz908,which may be due to the fact that the sea water has not completely withdrawn from the Bohai Sea with short time and temperature decline less than that of the Last Glacial Age.In the early MIS 3, a transgression has been occurred in cores of Lz908, YRD–1101, and BQ1 of the study area, but a fluvial deposit in cores of BT113 and BT114; from the middle and late MIS 3 to the Last Glacial Maximum, the study area was showed a regression during this period; there was have a marine bed due to wide transgression during the Holocene.

(2) According to the stratigraphic records of each borehole in the study area, we find that the evolution of the sedimentary environment is consistent with the trend of global sea level changes, indicating that stratigraphic development and the evolution of the sedimentary environment are mainly controlled by global sea level changes in the study area since the Late Pleistocene.

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