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Sedimentary records of natural and artificial Huanghe (Yellow River) channel shifts during the Holocene in the southern Bohai Sea

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ABSTRACT

Two gravity cores collected off the modern Huanghe (Yellow River) delta in the southern Bohai Sea were analyzed for grain size, the total organic carbon (TOC)/total nitrogen (TN) ratio, color diffraction, magnetic susceptibility, ^{14}C dating and ^{137}Cs and ^{210}Pb isotope contents to clarify changes in the sedimentary environment during the Holocene. In particular, the effect of natural and artificial river-course shifts of the Huanghe on the Bohai Sea sediment was investigated. A peat layer, scouring surface and sharp changes in the grain size, TOC/TN ratio, sediment color (L^*, a^*) and magnetic susceptibility were identified and are likely to be due to the early-Holocene sea-level rise resulting in environmental changes from coastal to shelf environments in the Bohai Sea. After the sea level reached its maximum at 6–7 ka BP, the lateral shifts in the river course of the Huanghe formed 10 superlobes, and superlobe 7 (11–1048 AD) and superlobe 10 (1855–present) of the Huanghe delta affected the core sites. The northern site of BH-239 has been more affected by the Huanghe since the middle Holocene. Notably, in the superlobe 10 period, the reshaping of the northern Huanghe delta due to an artificial river-course shift from northward to eastward in 1976 (e.g., $a\sim10$ km shoreline retreat due to coastal erosion) was recorded in the core sediments, particularly in terms of the TOC/TN ratio, sediment color (L^* and a^*) and magnetic susceptibility, owing to the huge sediment supply from coastal erosion of the former river mouth area.

1. Introduction

Sediment transported from rivers to the sea greatly affects the coastal sedimentary environment, especially in Asia (Hay, 1998). About 20 billion tons of river-borne sediment reaches the sea annually worldwide and large rivers in Asia contribute 30–40% of the world's sediment flux from the land to the sea (Milliman and Syvitski, 1992). These huge amounts of sediment transported from rivers to the sea are mostly confined to coastal and adjacent seas owing to relatively wide continental shelves, and mega-deltas on the Asian coasts formed during the middle to late Holocene after the sea level stabilized, e.g., the Huanghe (Yellow River) delta (Xue, 1993; Saito et al., 2000), Yangtze River delta (Hori et al., 2002), Red River (Song Hong) delta (Tanabe et al., 2006) and Mekong River delta (Ta et al., 2002, 2005).

The Holocene and recent changes of the Huanghe and their effects on the sedimentary environments of the deltaic coast and the Bohai Sea, Yellow Sea and East China Sea have interested many researchers because of the large sediment load and frequent shift of terminal channels (e.g., Ren and Shi, 1986; Xue, 1993; Martin et al., 1993; Hu et al., 1998; Saito et al., 2000; Wang et al., 2006, 2007). The Huanghe is the second greatest river in the world in terms of sediment load and it transported approximately 1.1×10^9 t of sediment to the sea annually during the period 1950–1980 (Milliman and Syvitski, 1992). It is estimated that the Huanghe has contributed about 2300 km^3 of sediment to the sea during the last 2300 years (Milliman et al., 1987). High sediment loads and steep river-channel gradients in the lower reaches have resulted in frequent shifts of the Huanghe channel (Saito et al., 2000). As a result, 10 superlobes, which formed the Huanghe delta, have been identified for the middle to late Holocene along the eastern coast of China (Xue, 1993) (Fig. 1). Moreover, the terminal channel of the Huanghe has slightly changed more than 50 times for superlobe 10 alone (1855–present) since the river began flowing into the Bohai Sea instead of the Yellow Sea (Pang and Si, 1979) (Fig. 2).

Extensive research has been carried out on the sedimentary environment and evolutional models of the Huanghe delta (Ye, 1982; Gao et al., 1989; Cheng and Xue., 1991), development of the Huanghe delta and the controlling factors (Pang and Si, 1979;

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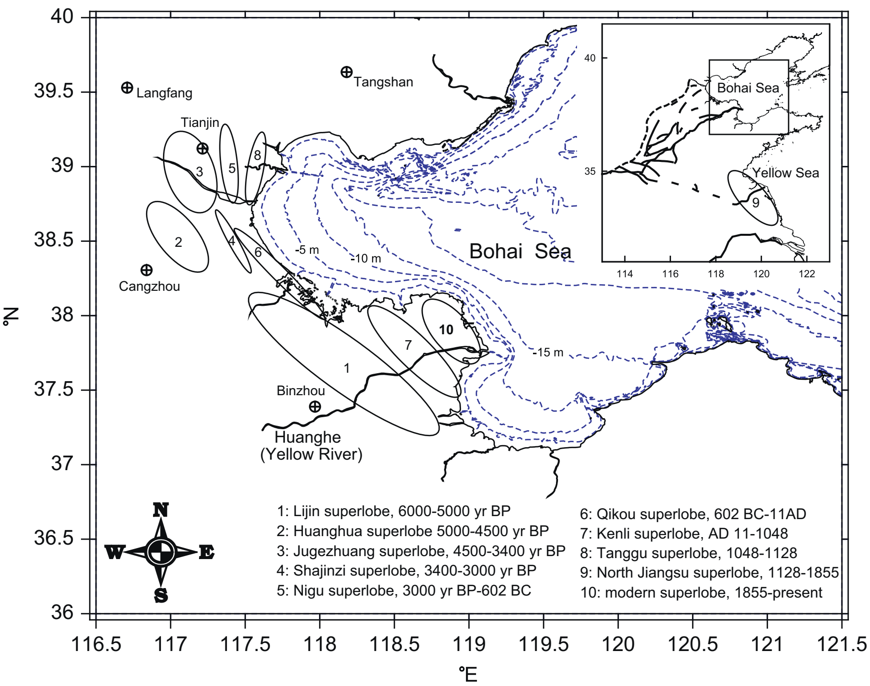

Fig. 1. Locations of the Holocene Huanghe deltas. The Holocene delta was divided into 10 superlobes by Xue and Cheng (1989), Xue (1993) and Saito et al. (2000).

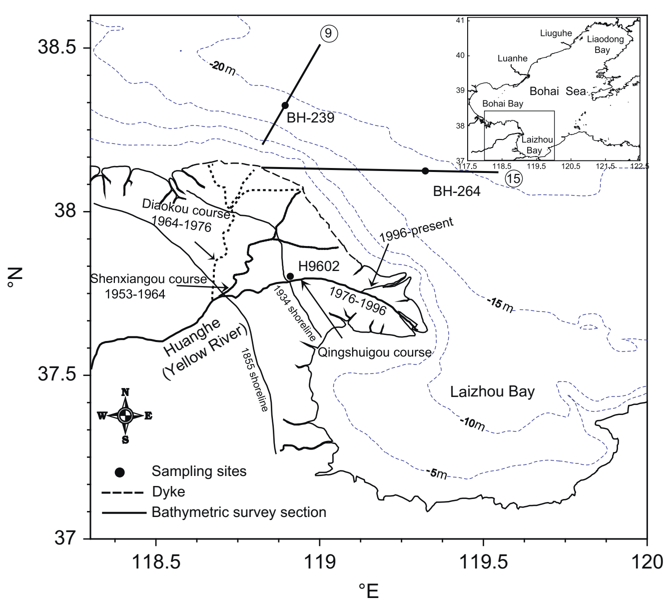

Fig. 2. Gravity core sites and three cross-shore sections, and the typical channel changes of the modern Huanghe delta. The shorelines in 1934 and 1855 were taken from Saito et al. (2000).

Zhang, 1984; Xue , 1993; Saito et al., 2000), and modern sedimentary processes off the Huanghe mouth and the effect of human activity (Wright et al., 1986; Li et al., 1998a, 1998b, 2000; Chu et al., 2006; Qiao et al., 2010). In the case of superlobe development during the Holocene, Xue (1993) and Saito et al. (2000) affirmed the existence of superlobes 1, 6, 7 and 10 and discussed the relationship between delta evolution and chenier development on the basis of sedimentary characteristics of the modern Huanghe delta and borehole samples (Fig. 1). Most of these works have carried out on-land survey and nearshore surveys of the Huanghe delta. On the other hand, Liu et al. (2009) discovered Huanghe-related sediment in a drilling core taken from the Bohai Sea. Liu et al. (2010b) measured the Holocene change in the effect of the Huanghe on the Bohai Sea sediment from analyses of magnetic susceptibility and calcite and muscovite contents and showed the strengthening effect of the Huanghe after ~2.4 cal. kyr BP.

This paper investigates the sedimentary record in the southern Bohai Sea and discusses the response to Huanghe channel shifts during the Holocene on millennial and decadal time scales, on the basis of detailed sediment analysis and dating data obtained for two cores off the Huanghe delta (Fig. 2).

2. Regional setting

The Bohai Sea is a semi-enclosed interior continental shelf sea of China, which is connected to the northern Yellow Sea by the narrow Bohai Strait (Fig. 1). The water depth is less than 30 m throughout the Bohai Sea, and depths exceeding 60 m can only be found in the northern part of the Bohai Strait (Qin et al., 1990) (Fig. 1). In the Bohai Sea, the tidal currents are dominant, although there are waves and ocean currents (Wei et al., 2004).

Many rivers of remarkably different size, water flow, and sediment discharge empty about 1.3×10^9 t of sediment per year into the Bohai Sea, with sediment discharge from the Huanghe accounting for about 93% during the late 1950s and early 1960s (Qin et al., 1990) (Fig. 1). The Huanghe is the most influential source of sediments for the Bohai Sea, not only at present but also during the Holocene. The Huanghe sediment discharge is mostly affected by human activity on millennial to decadal time scales (Wang et al., 2007). The sediment discharge was low during 2.5–10 kyr BP, while it suddenly increased to $\sim1.0\times10^9$ t over approximately the last 2000 years as a consequence of cultivation and deforestation on the Loess Plateau (Milliman et al., 1987; Ren and Zhu, 1994; Saito et al., 2001). However, the sediment load delivered by the Huanghe to the sea has decreased sharply since the late 1970s and reached 0.15×10^9 t during 2000–2005 because of effective soil conservation practices and the operation of dam reservoirs (Wang et al., 2007).

The Bohai Sea was subaerially exposed during the last glacial maximum, when the sea level was 120–130 m lower than the present level (Yang and Lin, 1993; Saito, 1998; Hori et al., 2001). The paleo-shoreline reached the present coastal position at ~8 kyr BP (Zhao et al., 1979) and reached the Holocene maximum transgression at ~6–7 kyr BP in the Bohai Sea area. After the sea level was highest during the middle Holocene, it oscillated slightly and then fell to the present level (Zhao et al., 1979; Xu, 1994). The sedimentary environments since the last glacial maximum changed from river and lake environments to tidal flats and estuaries related to early-Holocene transgression, then to shallow marine or deltaic environments related to further sea-level rise and stable sea levels (Qin et al., 1990; Xue et al., 1995). The initiation of the Huanghe delta is not yet clear; however, the delta can be divided into 10 superlobes since the middle Holocene. Nine of the 10 superlobes formed on the western coast of the Bohai Sea and one on the western coast of the Yellow Sea during the period 1128–1855 (Xue, 1993) (Fig. 1). The Yangtze River delta has been affected by the Huanghe ever since its shift to the Yellow Sea (Liu et al., 2010a).

The present Huanghe delta formed after an artificial river-course shift in 1855 from the Yellow Sea to the Bohai Sea, which is referred to as superlobe 10 (Figs. 1 and 2). Ten river courses have been discriminated for superlobe 10. Recent river-course shifts have been from the Shenxiangou course to the Diaokou course in 1964, and from the Diaokou course to the Qingshuigou course in 1976 (Fig. 2). The artificial course change in 1976 from northward to eastward in particular has resulted in serious coastal erosion in the northern part of the delta; e.g., a ~10 km shoreline retreat and delta front erosion in the nearshore zone (Wang et al., 2006).

3. Material and methods

Two gravity cores BH-239 and BH-264 were collected in the southern Bohai Sea around the modern Huanghe delta in August 2007 (Fig. 2 and Table 1) by the R/V *Kan407* of the Shanghai Bureau of the Marine Geology Survey. The cores were first scanned by an MS2 Magnetic Susceptibility System for susceptibility analysis and then cut lengthwise into two halves at the laboratory of the First Institute of Oceanography. The sediment color was recorded using a Minolta CM-2002 spectrophotometer. Sub-samples at intervals of 2 cm were taken for analyses of gain size, total organic carbon (TOC) and total nitrogen (TN).

Grain sizes of sediment samples were measured using a Malvern Mastersizer 2000 instrument after pretreating with 30% H_2O_2 and 1 mol/l HCl to decompose the organic matter and remove carbonates (908 Project Office, 2006). The samples were analyzed for TOC and TN with a CHN analyzer (Vario EL III) after they were freeze-dried, pulverized and treated with 1 mol/l HCl to remove carbonate. The precision is $\leq 0.2\%$ as determined by repeated measurements (908 Project Office, 2006).

Accelerator mass spectrometry (AMS) ^{14}C dating was performed on mixed benthic foraminifers at the Woods Hole Oceanographic Institution, USA. Radiocarbon ages were converted using Calib v. 6.0.1 to calibrate calendar ages using ΔR of -138 ± 67 yr (Stuiver and Reimer, 1993; Southon et al., 2002) (Table 2). ^{137}Cs and ^{210}Pb were measured employing EG&G Ortec Gamma Spectrometry at the Institute of Limnology and Geography, Nanjing, China. The sediment samples were air-dried and pulverized, and ^{137}Cs and ^{210}Pb concentrations were then determined from gamma emissions at 662 and 46.5 keV, respectively.

Table 1
Locations, water depths and core depths of cores BH-239 and BH-264.

	Longitude (°)	Latitude (°)	Water depth (m)	Core depth (cm)
BH-239	118.91026	38.32195	19.3	295
BH-264	119.32265	38.14543	20.1	295

Table 2
^{14}C ages of mixed benthic foraminifera in cores BH-239 and BH-264.

Sample	Depth (cm)	AMS^{14}C age (yr BP)	Delta ^{13}C	Calibrated age (cal. yr BP)	
				Intercept	Range (1σ)
BH-239-123	244–246	4640 ± 35	-2	5030	4946–5139
BH-264-56	110–112	4650 ± 35	-2	5040	4963–5197
BH-264-115	228–230	7430 ± 50	-2	8005	7955–8103

4. Results

4.1. Lithology, grain-size composition, TOC/TN ratio, magnetic susceptibility, color reflectance L* and a*, and ^{14}C date

Core BH-239: The sediment core has two main units on the basis of lithology and sediment characteristics. The lower unit from 277 to 295 cm consists of peat and clayey silt sediments and correlates with previously reported early-Holocene coastal sediments (e.g., Saito et al., 2000; Liu et al., 2009). The overlying upper unit with an erosional surface at 277 cm consists of shallow marine clayey silt to sandy silt sediments and can be divided into four parts – 0–55, 55–95, 95–177 and 177–277 cm – on the basis of sediment characteristics, particularly cyclic changes (an upward fining succession) in grain size and characteristics of TOC/TN ratios, magnetic susceptibility, and *L** and *a** values. ^{14}C dating of benthic foraminifera from 244 to 246 cm gives a date of 5030 cal. yr BP (Table 2).

Sediment in the upper 55 cm mainly consists of light yellowish brown and greenish gray silt with sand content less than 1.5% (Fig. 3). Notably, sediment in the 6–40 cm layer is light yellowish brown and has the highest TOC/TN ratio and *L** and *a** values (Fig. 3). Sediment in the 55–177 cm layer is yellowish brown silt with low sand content, while sediment in the 55–95 cm layer has lower TOC/TN ratios and *L** and *a** values but higher magnetic susceptibility compared with the 95–177 cm layer. Sand content in the 95–177 cm layer is a little higher than that in the 55–95 cm layer. Yellowish brown sandy silt is observed at 177–277 cm with low TOC/TN ratios, magnetic susceptibility, and *L** and *a** values. It is noteworthy that a scouring surface is detected at 277 cm with sand content greater than 35%, and there is a peat layer from 283 to 292 cm. Accordingly, the minimum magnetic susceptibility, and *L** and *a** values are observed in the 277–295 cm layer (Fig. 3).

Core BH-264: The sediment core again has two main units on the basis of lithology and sediment characteristics (Fig. 4). The lower unit from 215 to 295 cm consists of pale yellowish gray sandy silt, and silt from 228 to 230 cm has a ^{14}C date of 8005 cal yr BP (Table 2). Some mollusk shell fragments are observed at 235, 245 and 271–295 cm. There are thick sand-pipe-type burrows at 264–268 cm. This sediment facies is interpreted as coastal and estuarine sediments in the early Holocene and corresponds to the lower unit of core BH-239. The overlying upper unit consists of yellowish brown shallow marine clayey silt to sandy silt sediments and is further divided into three parts – 0–25, 25–115 and 115–215 cm – on the basis of the sediment characteristics of the TOC/TN ratio, magnetic susceptibility, and *L** and *a** values. The ^{14}C date of benthic foraminifera from 110 to 112 cm is 5040 cal yr BP (Table 2).

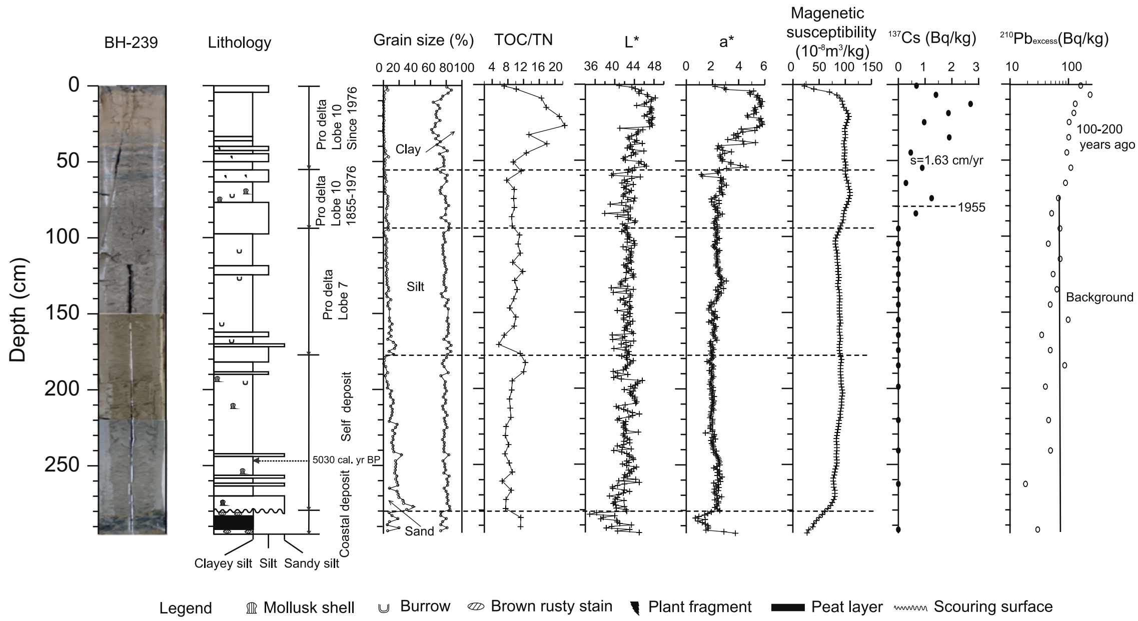

Fig. 3. Photograph, lithology, grain size, TOC/TN ratios, color reflectance L^* and a^*, magnetic susceptibility and activity profiles for ^{137}Cs and ^{210}Pb of gravity core BH-239.

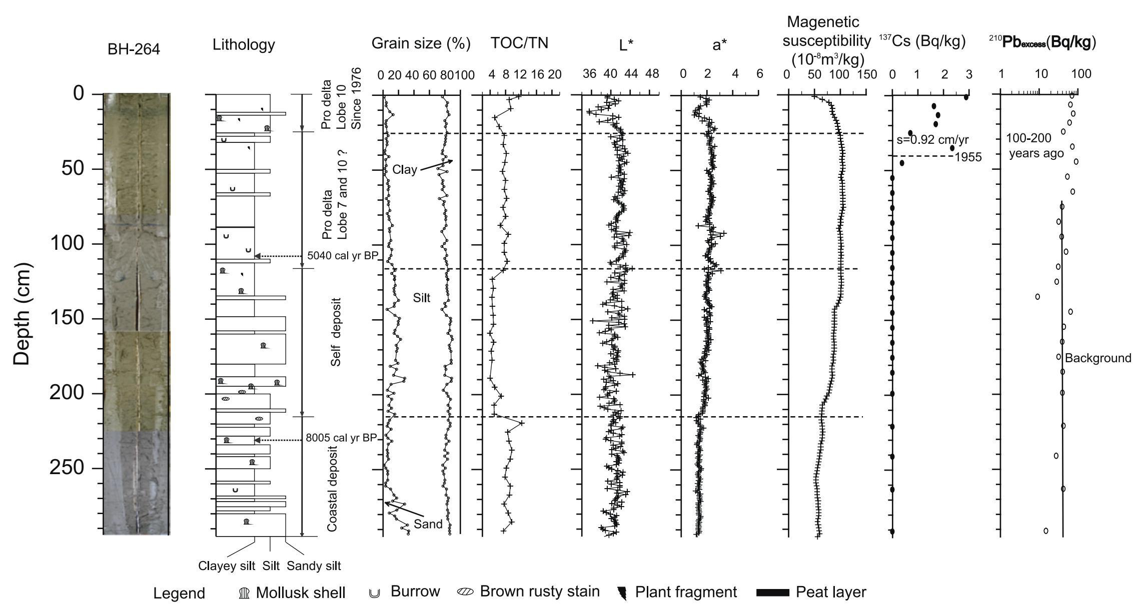

Fig. 4. Photograph, lithology, grain size, TOC/TN ratios, color reflectance L^* and a^*, magnetic susceptibility and activity profiles for ^{137}Cs and ^{210}Pb of gravity core BH-264.

Sediment in the upper 25 cm is silt with sand content of ~5.3%, and the sand content increases gradually to 7.8% at 115 cm. The TOC/TN ratio, magnetic susceptibility, and L^* and a^* values fluctuate significantly in the 0–25 cm layer. In comparison, the TOC/TN ratio, magnetic susceptibility, and L^* and a^* values remain stable at ~7.7, $\sim 102 \times 10^{-8}$ m^3/kg, ~42 and ~2.3, respectively in the 25–115 cm layer. Sediments at 115–215 and 263–295 cm are slightly coarser sandy silt with the sand content reaching ~17.0%, and silt sediments are dominant at 215–263 cm with a sand content of ~6.9%. The TOC/TN ratio is less than 6 and the a^* value and magnetic susceptibility higher than 2 and 80×10^{-8} m^3/kg, respectively, in the 115–215 cm layer. In sharp contrast, the sediment in the 215–295 cm layer has higher TOC/TN ratios, with the average ratio being higher than 8.

4.2. ^{137}Cs and ^{210}Pb profiles

The ^{137}Cs isotope began to appear in environmental samples at measurable levels from about 1955 and was most prevalent in 1963 (e.g., Palinkas and Nittrouer, 2007). Subsurface peaks are not discernible in profiles of ^{137}Cs in the cores taken off the Huanghe mouth (Figs. 3 and 4). However, the deepest onset of ^{137}Cs is a useful time marker for about 1955. Correspondingly, the average sedimentation rate is 1.63 cm/yr in the upper 85 cm of core BH-239 and 0.92 cm/yr in the upper 48 cm of core BH-264.

Generally, the ^{210}Pb$_{ex}$ activity is used to calculate the sedimentation rate where sediment stably accumulates for appropriate periods and ^{210}Pb$_{ex}$ profiles show a decline downward with decay of ^{210}Pb. However, the down core variation of ^{210}Pb$_{ex}$ for cores BH-239 and BH-264 does not show such clear trend and $^{210}Pb_{ex}$ of the upper parts of the cores is not so large when compared with the lower background values. Therefore it is hard to calculate sedimentation rates under the premise that the initial flux of ^{210}Pb is constant. As the presence of excess ^{210}Pb can be used to estimate a minimum accumulation rate, the detection of excess ^{210}Pb employing analytical techniques is limited to approximately five half-lives (i.e., ~100 years) (Crockett et al., 2008). It is determined that the sediments in the upper 75 cm of core BH-239 and in the upper 70 cm of core BH-264 were deposited during the past 100 years.

5. Discussion

5.1. Early-Holocene environmental change

Generally, the Bohai Sea is a subsiding basin where sediment more than 400 m thick has accumulated since the Quaternary (Qin et al., 1990). Because the average water depth is only 18 m, the sedimentary sequences off the Huanghe mouth are mainly controlled by the sea level near the Bohai Sea and sediment supply from the Huanghe (Fig. 1).

A peat layer is observed in core BH-239 at 283–292 cm (Fig. 3), indicating a prevailing fluvial or lacustrine or coastal marsh sedimentary environment during 8000–10000 yr BP in the Bohai Sea (Qin et al., 1990; Xue, 1993; Saito et al., 2000). The lower units of the two cores indicate a coastal estuarine environment, which correlates to early-Holocene coastal sediments previously reported (Qin et al., 1990; Xue, 1993; Saito et al., 2000; Liu et al., 2009, 2010b). The Holocene transgression of the Bohai Sea began ~8500 yr BP (Qin et al., 1990). Related to a rise in the sea level from −36 to −16 m between ~9800 yr BP and 9000 yr BP in the Western Pacific (Liu et al., 2004), the locations of cores BH-239 and BH-264 (with water depths are 19.3 and 20.1 m, respectively) were submerged via marine inundation and the sedimentary environment changed from a terrestrial (fluvial or lacustrine) environment to a coastal marine environment.

The sediments of the lower part of the upper unit in BH-264 have low TOC/TN ratios ranging from 4 to 6 and relatively coarse and mollusk-rich sediment with a low accumulation rate of 0.4 mm/yr, which is determined by two AMS ^{14}C ages (5040 cal. yr BP at 110–112 cm and 8005 cal yr BP at 228–230 cm). As low TOC/TN ratios indicate a marine origin for organic matter, this is interpreted as a condensed section in the Bohai Sea during maximum marine transgression in the middle Holocene. Palynological analysis shows that the climate became warmer and wetter after ~7600 cal. yr BP (Yi et al., 2003). A previous study showed that the Holocene transgression reached its maximum at about 6000 C-14 yr BP (6700 cal. yr BP; Qin et al., 1990). A scouring surface identified above the peat layer in core BH-239, overlain by shallow marine sediments, is interpreted as a ravinement surface, also indicating a rapid sea-level rise after the depositional of coastal sediments (Fig. 3). It is thus concluded that the study area had coastal to shelf environments related to a rise in the sea level during the early to middle Holocene.

5.2. Delta-lobe shifts recorded in cores on a millennial time scale

According to historical remains that bound delta superlobes and cheniers, nine delta superlobes are discriminated on the deltaic coast of the western Bohai Sea (Fig. 1). Superlobe 1 (6000–5000 C-14 yr BP), superlobe 7 (1939–902 yr BP; 11 AD–1048 AD) and superlobe 10 (1855–present) have gradually approached both core sites, which are located near the present Huanghe delta (superlobe 10; Xue, 1993). During the period 1128–1855, the Huanghe flowed directly to the Yellow Sea. Its course then suddenly changed to the Bohai Sea in 1855. This abrupt change was recorded in borehole core H9602 taken on the delta plain of superlobe 10 (Saito et al., 2000). Deltaic sediments of superlobe 10 with a thickness of 17.5 m directly overlie superlobe 7 deltaic sediments with a thickness of 4 m at the H9602 site (Fig. 2).

This abrupt change in the Huanghe course is also recorded in cores BH-239 and BH-264. On the basis of ^{137}Cs and ^{210}Pb chronology, an abrupt change at 95 cm in core BH-239 corresponds to the abrupt change in 1855. When the Huanghe began emptying into the Bohai Sea in 1855, the terminal channel was mainly in the center of the modern Huanghe delta lobe (Pang and Si, 1979) (Figs. 1 and 2). In core BH-264, this change is not clearly indicated by sediment facies; the change would correspond to a depth of 115–25 cm.

For the superlobe 1 period (6000–5000 C-14 yr BP), sediment facies show shelf mud in cores BH-239 (177–277 cm) and BH-264 (115–215 cm). The BH-239 site is more affected by the Huanghe in that it has higher TOC/TN ratios. Superlobe 7 corresponds to the interval 95–177 cm in core BH-239 and perhaps the interval 25–115 cm in core BH-264. The sediment thickness also shows that the BH-239 site was more affected by the Huanghe in this superlobe period. TOC/TN ratios in both cores increase as the depth decreases, indicating an increase in terrigenous (Huanghe) effects resulting from delta progradation. If we compare TOC/TN ratios for the same superlobe periods of both cores, core BH-239 has higher values than BH-264, indicating that BH-239 has been more affected by the Huanghe in the last 6000 years.

5.3. Effects of coastal erosion on the Huanghe delta

During the superlobe 10 period that commenced in 1855, the Huanghe changed its course within the superlobe. Particularly in 1976, the river course changed from northward (Diaokou course) to eastward (Qingshuigou course) (Fig. 2). After this course shift, there was serious coastal erosion in the former river mouth area of the Diaokou course. The shoreline retreated by approximately 10 km and the former delta front was eroded to a water depth of ~11–14 m in the nearshore zone (Wang et al., 2006; Chu et al., 2006). A huge amount of sediment was redistributed in this area and transported offshore.

These drastic changes are recorded in both cores, particularly in core BH-239. Sediment in the upper 55 cm, especially at 6–40 cm in core BH-239, is characterized by high clay content, high TOC/TN ratios, and high L^* and a^* values (Fig. 3). These values are the highest for the core. In particular, the TOC/TN ratio is greater than 16, indicating a terrigenous origin, and high a^* value corresponding to a more reddish color indicates the possibility of a greater inclusion of soil. According to ^{137}Cs chronology, the abrupt change at 55 cm in core BH-239 corresponds to the 1976 river-course shift. Huge amounts of tidal marsh and soil on land have been eroded and transported directly offshore.

Water-depth changes in the nearshore zone of the Huanghe delta including the core sites were reported by Wang et al. (2006) (Fig. 5). The water depth at the location of core BH-239 was about 19.0, 19.2, 18.3 and 18.7 m in 1976, 1986, 1996 and 2004, respectively. This shows that the northern Huanghe delta eroded significantly during 1976–1986 because of the shortage of sediment supply due to the river-course shift in 1976. The nearshore area of the delta was continuously eroded; however, the offshore area including the location of core BH-239 has received much fine-grain sediment supplied by coastal erosion in the coastal to nearshore zone during 1986–2004 (Figs. 3 and 5). Fig. 5 shows a similar phenomenon at the location of core BH-264. Core BH-264 is far from, yet was affected by, the present and former river mouths of the Huanghe; therefore, sediment characteristics recorded in core BH-264 have different patterns and are less

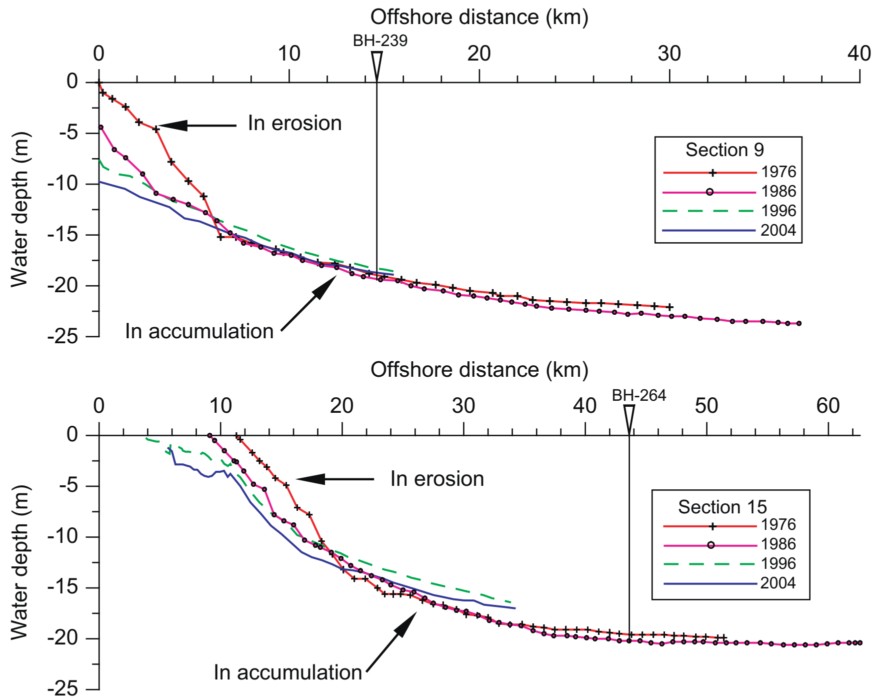

Fig. 5. Typical cross-section of the modern Huanghe delta (1976–2004). The locations of sections 9 and 15 are shown in Fig. 2.

obvious compared with those recorded in core BH-239 (Figs. 3 and 4).

6. Conclusion

Two gravity sediment cores taken around the Huanghe delta in the Bohai Sea have recorded well the environmental changes due to Holocene sea-level changes, natural river-course shifts of the Huanghe on a millennial time scale, and artificial river-course shifts on centennial to decadal time scales. The main results of analyses for sediment facies, grain size, TOC/ TN ratio, color diffraction (L^* and a^*) and magnetic susceptibility, in conjunction with radioisotope chorolonogy by ^{14}C, ^{137}Cs and ^{210}Pb, are summarized as follows:

(1) A peat layer, mollusk shell fragments, thick sand-pipe-type burrows and low values of magnetic susceptibility and color indicators of L^* and a^* characterize the lowermost part of the core, which is interpreted as coastal estuarine environment in response to early-Holocene transgression.
(2) A sharp bounding surface between coastal estuarine sediments and overlying shelfal sediments together with sharp changes in grain size, TOC/TN ratio, L^* and a^* values and magnetic susceptibility was identified at 7–8 cal. kyr BP, illustrating a rapid deepening related to early-Holocene sea-level rise.
(3) Lateral shifts of the river course of the Huanghe and delta progradation since the middle Holocene have affected sediment characteristics of the Bohai Sea, which have been recorded in the sediment cores. Particularly the shifts related to superlobe 7 (11–1048 AD) and superlobe 10 (1855–present) of the Huanghe delta were recognized in the cores, which were identified in terms of changes of grain size, color (L^*, a^*), TOC/TN ratio, accumulation rate and magnetic susceptibility.
(4) The artificial river-course shift from the Diaokou course to the Qingshuigou course in 1976 during the superlobe 10 period was well preserved in the cores. Particularly sediment supply from the former river mouth area (Diaokou mouth) to offshore by severe coastal erosion after the course shift has impacted sediment facies of the BH-239 core, which are characterized by high clay content, high TOC/TN ratios, high L^* and a^* values.

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